Report No. CG-D-29-97

Feasibility Study Of Repowering the USCGC VINDICATOR (WMEC-3) With Modular Diesel Fueled Direct Fuel Cells

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Final Report
May 1997

This document is available to the U.S. public through the
National Technical Information Service, Springfield, Virginia 22161

Prepared for:

U.S. Department of Transportation
United States Coast Guard
Operations, (G-O)
Washington, DC 20593-0001

19980217 555

and

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Technical Report Documentation Page

1. Report No. CG-D-29-97	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Feasibility Study of Repowering the USCGC VINDICATOR (WMEC-3) With Modular Diesel Fueled Direct Fuel Cells		5. Report Date May 1997 6. Performing Organization Code Project No. 3310.2
7. Author(s) William H. Kumm and Homer L. Lisle, Jr.		8. Performing Organization Report No. R&DC 12/97
9. Performing Organization Name and Address Arctic Energies LTD. (AEL) 511 Heavitree Lane Severna Park, MD 21146-1010		10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTCG39-96-C-E00047
12. Sponsoring Agency Name and Address U.S. Department of Transportation United States Coast Guard Operations, (G-O) Washington, DC 20593-0001	U.S. Coast Guard Research and Development Center 1082 Shennecossett Road Groton, CT 06340-6096	13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code Commandant (G-OCU) U.S. Coast Guard Headquarters Washington, DC 20593-0001

15. Supplementary Notes

The R&D Center's technical point of contact is Dr. Stephen Allen, 860-441-2731.

16. Abstract

In 1988, AEL was awarded a Small Business Innovation Research (SBIR) Phase I contract on Navy Topic N88-94 by the NAVSEA R&D Officer, Code 03R. In 1990, this topic moved to Phase II with a contract involving the lab demonstration of the use of diesel type fuel in high temperature molten carbonate or Direct Fuel Cells (DFCs). The Phase II work was successfully completed in 1992. In 1995, Navy Code 03R agreed to transfer Topic N88-94 to the USCG R&D Office, G-SIR. The Phase III Feasibility Study was awarded to AEL in 1996 to perform the work described in this report.

The USCGC VINDICATOR (WMEC-3) has been evaluated as the candidate ship for fuel cell repowering at 2.58 MW. It is a former T-AGOS ship with diesel-electric propulsion and ship's service. The four 600 kW diesel generators (2.4 MW) would be replaced with twelve 215 kW DFC one-sided-fit fuel cell modules embodying a "no-maintenance" rapid changeout approach. The repowered ship would be faster, consume half of the fuel for the equivalent range, be super-quiet, be air pollution-free, cut the crew complement and produce potable water onboard as a byproduct. The study evaluated technical aspects of fuel cells, naval architectural removals and additions, maintenance, risk and cost-effectiveness issues. The use of electric utility type DFCs, with the cost reduction and mass production advantages of this on-land marketplace will make possible early introduction of marine-derivative fuel cell power plants for ship applications.

It is concluded that repowering ships with fuel cells is feasible and that the next step is a Preliminary Design.

17. Key Words	18. Distribution Statement
feasibility study repowering USCG diesel-electric drive ships direct fuel cells	This document is available to the U.S. public through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)	20. SECURITY CLASSIF. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED		

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METRIC CONVERSION FACTORS

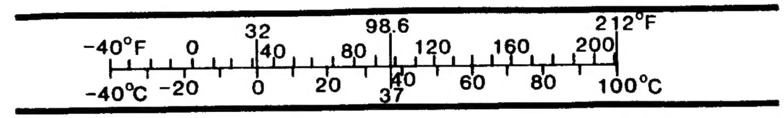
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly).

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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GLOSSARY OF TERMS

AEL .... Arctic Energies Ltd
APU .... Auxiliary Power Unit
ASF .... Amps per Square Foot area of a fuel cell
BSFC .... Brake Specific Fuel Consumption, in lbs/hph, kg/kwh or metric tons/MWh
BTU .... British Thermal Unit
CFM .... Cubic Feet per Minute
dB .... Decibels
DFC .... Direct Fuel Cells or internally reforming molten carbonate fuel cells
DOE .... Department Of Energy
EPRI .... Electric Power Research Institute
ERC .... Energy Research Corporation
FCM .... Fuel Cell Module
FCMC .... Fuel Cell Manufacturing Corporation
G2 .... Real time expert system software
GENSYM .... General Simulation Corporation
GPD .... Gallons Per Day (24 hours)
GPM .... Gallons Per Minute
GRI .... Gas Research Institute
JP8 .... Federal Specification Jet fuel currently with up to 3,000 PPM of sulfur
kW .... kilowatt
LHV .... Lower Heating Value
LSMD .... Low-sulfur Motor Diesel, less than 500 PPM
MCFC .... Molten Carbonate Fuel Cell (external or internal fuel reforming)
MTBF .... Mean Time Between Failure
MW .... Megawatt
NASA .... National Aeronautics and Space Administration
NAVFAC .... Naval Facilities Command
NSF/OPP .... National Science Foundation/Office of Polar Programs
OTA .... Congressional Office of Technology Assessment
PAFC .... Phosphoric Acid Fuel Cell
PEMFC .... Proton Exchange Membrane Fuel Cell
PPM .... Parts per million by weight
PSIA .... Pounds per Square Inch Absolute
SURTASS .... Navy T-AGOS Surveillance Towed Array Sensor
SFDFM .... Sulfur-free Diesel Fuel-Marine
SFJP8 .... Sulfur-Free JP8, less than 1 PPM
SFJP5 .... Sulfur-Free JP5, less than 1 PPM
SFMD .... Sulfur-Free Motor Diesel, less than 1 PPM
SHP .... Shaft Horse Power
SITREP .... Situation Report
SOFC .... Solid Oxide Fuel Cell
SWBS .... Ship Weight Breakdown System
T-AGOS .... Navy Ocean Surveillance Ship
THERM .... Metric unit of heat
USCG .... United States Coast Guard
VAC .... Volts, Alternating Current
VDC .... Volts Direct Current

EXECUTIVE SUMMARY

The 1996 work described in this Report came about as a result of multi-year ongoing efforts by Arctic Energies Ltd. (AEL), the contractor, since the successful completion of SBIR Topic N88-94 Phase II work for NAVSEA in 1992 *"...in which a laboratory demonstration was carried out on the internal reformation of diesel powered fuel cells. This SBIR demonstrated that it is feasible to proceed with a prototype fuel cell installation on board ship."**

In 1995 the Topic N88-94 Project management leadership was transferred to the USCG, with the agreement of NAVSEA, because the NAVSEA did not have adequate funding available in FY 1993, 1994 and 1995 to move the Project into the Advanced Technology Development (ATD) status. In January 1995 the Navy agreed in writing to provide appropriate co-funding of the USCG-led Project when it became available. A "Green Technology" hardware demonstration of fuel cell propulsion on a federal ship should be done as soon as possible.

All the federal agency ship operators will actually save in at least five ways:

1. Lower acquisition cost due to early commercialization of the fuel cell technology derived from the electric utility marketplace.
2. Half the fuel required over the ship life.
3 Cutting the fuel required also cuts the ship's exhaust thermal signature dramatically.
4. Smaller crews and thus less personnel cost.
5. Air pollution-free operation with the "best available technology" thus eliminating future penalty fees for air pollution in "home ports" or ports of call.

For some ship operators another important advantage is:

6. Acoustically quiet operations. For many applications from NOAA fisheries research, to Navy ASW, to USCG at-sea rescue operations or stealthy tracking of contraband carrying ships in the US coastal zone, a super-quiet ship is more and more important. Fuel cells make <u>NO</u> noise.

The Objective of the FUEL CELL PROPULSION FEASIBILITY STUDY is:

> *"... to conduct a feasibility study of the replacement of an existing T-AGOS vessel of the diesel-electric propulsion system with fuel cell propulsion. This study will identify technical design issues and cost considerations involved in this replacement and is the first step leading to the operational T-AGOS vessel powered by fuel cells."**

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* Quotations are taken directly from the USCG Contract DTCG39-96-C-E00047 Task Statement 2/14/96 titled "FUEL CELL PROPULSION FEASIBILITY STUDY".

The key to carrying out the Objective has been the precise engineering definition of the repeating one-sided-fit fuel cell power plant modules. This has been done. The module design is both practical and buildable. At a 6 ft tall fuel cell stack size, with 216 individual cells, the power output per module is calculated to be 215 kW. Thus twelve (12) such 8 ft long, 3.5 ft wide and 7 ft tall modules will provide the needed 2.4 MW to 2.58 MW. They will be placed in the former "engine room", now "fuel cell room", in four rows (fore-aft) with three modules per row (athwartships).

Section 1 provides a brief background on the Project and the objectives of the study.

Section 2 is the fuel cell technology overview. It shows why the modularized electric utility type DFC technology is the recommended, and available, fuel cell technology.

Section 3 provides information on the baseline ship configuration as modified by the USCG from the earlier Navy ASW mission-configured T-AGOS ship.

Section 4 focuses on the fuel cell power system technical design and the repowered ship performance assessment.

Section 5 addresses the detailed fuel cell specification which would need to be prepared.

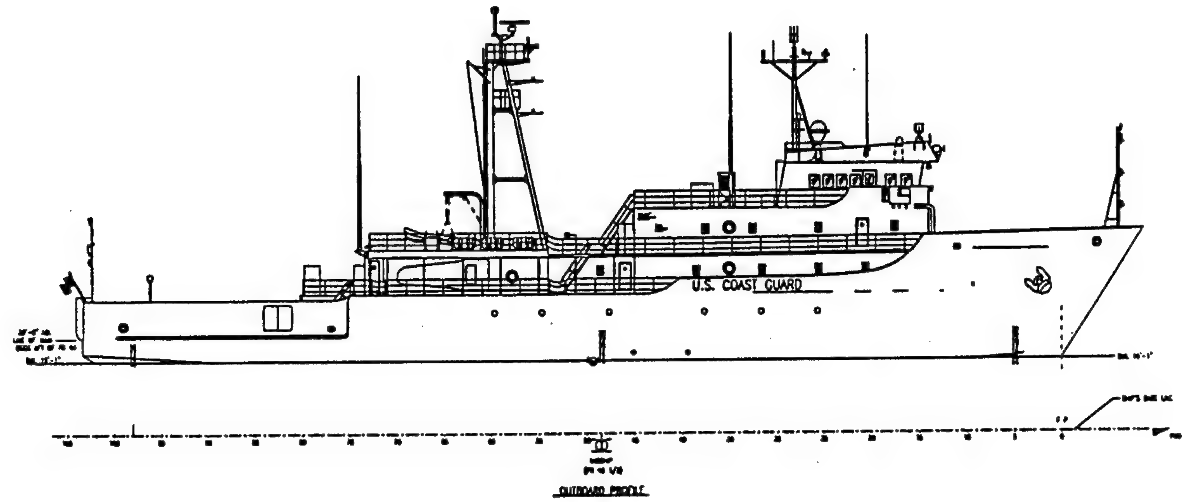
Section 6 provides the cost analysis and the projected operational cost savings analysis.

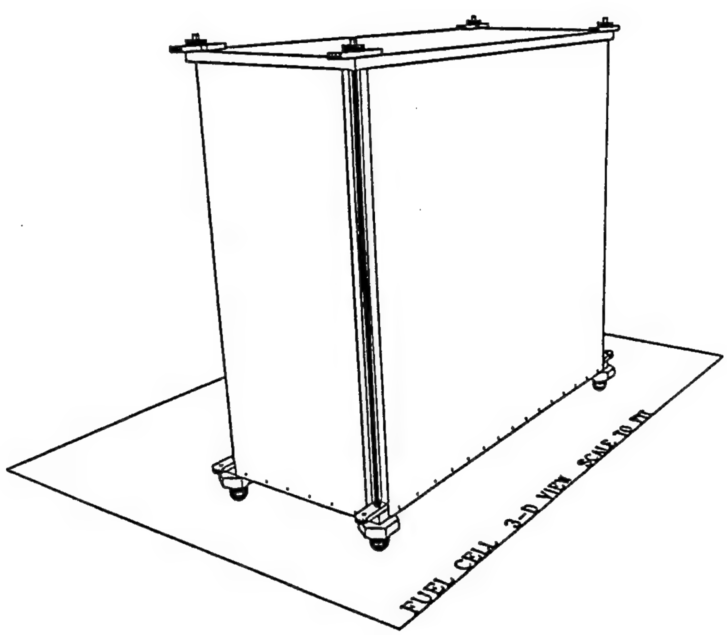
Section 7 summarizes the Study.

Section 8 contains the REFERENCES.

FRONTISPIECE

"STACK-FREE" FUEL CELL POWERED WMEC-3 VINDICATOR





T-AGOS Class - USCGC VINDICATOR (WMEC-3)

1. INTRODUCTION

1.1. Purpose

The purpose of this study is to provide a sufficient level of technical and cost detail to confirm the near term potential to repower the USCGC VINDICATOR (WMEC-3) Class with diesel fueled molten carbonate fuel cell modules and provide the necessary feasibility detail needed to plan and contract for the repowering after a preliminary design, contract definition and detail design phase.

1.2. Background

The U.S. Coast Guard has embarked on an integrated evaluation of marine-application diesel fueled molten carbonate fuel cells derived from the land based electric utility industry. This initiative is being coordinated with both the Naval Engineering and the Research and Development Offices of the U.S. Coast Guard. This Report will aid the U.S Coast Guard, the Department of Transportation as well as other ship-operating agencies in the process of understanding the potential of fuel cells and solving the near term environmental problems of existing ships while dramatically reducing the consumption of fossil fuels. The U.S. Coast Guard is extending the work started by the U.S Navy in the period 1988 to 1992 (under SBIR Topic N88-94) by identifying an application for the first use of fuel cells for ship propulsion in the multi-megawatt size using liquid logistics fuel. The many attractive performance advantages demonstrated in this feasibility study are expected to attract cost sharing from many Federal Government agencies and from private industry marine users.

1.3. Objectives

The Objective is to conduct a feasibility study of the replacement of an existing T-AGOS vessel of the diesel-electric propulsion system with fuel cell propulsion. This study will identify technical design issues and cost considerations involved in this replacement and is the first step leading to the operational T-AGOS vessel powered by fuel cells.

1.4. Assumptions

The assumptions used in the analyses were conservative and reflect simplified parameters which allow generalizations to be developed so that a rapid assessment of a repowering of the T-AGOS ship could be carried out. These assumptions are as follows:

- Molten carbonate fuel cells are the most available and appropriate based on prior research.[*4,5,6]

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* Superscript numbers refer to Section 8 REFERENCES by number.

- Sulfur-Free Diesel Fuel Marine (SFDFM), Sulfur-Free JP5 (SFJP5) or Sulfur Free Jet Fuel 8 (SFJP8) are the fuels of choice based on cleanliness, energy density, environmental and logistic considerations. It is important to limit the sulfur content to less than 1 PPM to prevent deactivation of the catalyst used in the fuel reformation. This is most readily accomplished at the oil refinery. Various US refineries can supply sulfur-free diesel fuel. When there is no sulfur in the fuel no sulfur dioxide atmospheric pollution will result.

- The repowering would totally replace the existing four 600 kW diesel generator sets and their auxiliary or balance-of-plant (BOP) equipments.

- The sound isolation "bedplates" and related equipment for the four diesel generator sets would be disassembled and removed.

- Corrections to trim and stability would be necessary because of the removal of U.S. Navy mission equipment and the installation of USCG equipment. This USCG configuration was the diesel engine generated baseline from which the fuel cell powered ship was derived.

- A notional mission profile was used to illustrate the full effects of the tradeoffs.

- Ship classing and certification would remain at the same level or requirement.

1.5. Approach

Practical considerations concerning the near term inclusion of fuel cell technology in any ship dictates that the analysis be conducted in such a manner that measures the potential gains in the ship characteristics against the cost of repowering and subsequent operation. Separate analyses of the engineering and the cost are necessary. The engineering analysis of the ship characteristics and naval architectural margins expressed as additions and deletions of equipments, structure and supporting systems which would be impacted by the fuel cell modules. The implementation of the technology provides the basis for deriving the "deltas" from the conventional baseline and are used in the cost analysis. Fuel cell technology implementation in the propulsion system is based on providing equivalent or better functionality and integrity. Direct effects on ship characteristics, and secondary effects on naval architectural margins, resulting from fuel cell technology are quantified. Evaluation of potential effects on construction procedures have been addressed.

The cost analysis used the quantified impacts in the areas of ship characteristics and naval architectural margins to determine the economic first costs associated with implementing fuel cell technology in ship repowering and new ship construction. Life cycle cost analysis of the operation was also included to show the payback estimate. Safety, maintenance and risk reduction were assessed in separate analyses.

2. FUEL CELL TECHNOLOGY OVERVIEW

2.1. Direct Fuel Cell Technology

This section explains the basis of the technology and how molten carbonate fuel cells operate. We have drawn from the 1989 "Fuel Cell Handbook",[7] and other sources[8,10,11]. Previous application analyses and direct experimental data from DFCs in the process of commercialization have been reviewed. The following is paraphrased from the Handbook and other sources, with regard to molten carbonate fuel cells or, when using internal fuel reformation, as they are now coming to be known as Direct Fuel Cells (DFCs).

A conceptual diagram of a single DFC plate is contained in Figure 2-1. Each repeating cell element is made up of 1) an anode, where oxidation of the fuel occurs; 2) an electrolyte, to enable the ion transfer process and separate the anode and cathode; and 3) the cathode where the reduction of the oxidant occurs. Figure 2-2 shows a cutaway drawing of a cell of a molten carbonate fuel cell or DFC stack. The physical configuration of an air cooled, internally reformed DFC is simplified in the illustration. All plates allow cooling and the middle plate is the endothermal chamber which would be used in the reforming of the diesel fuel. Plates above and below contain molten carbonate in a catalyst matrix adjacent to collection plates. The bipolar plates are typically made of nickel alloy stainless steel. The cathode and anode electrodes are in contact with the diffusion electrodes consisting of a porous agglomerates of catalysis particles held together with a teflon binder and backed by a porous sheet. The hydrogen from the anode diffuses through pores to a catalyst agglomerate made up of electrically conductive catalyst particles of molten carbonate. When the hydrogen arrives at the reaction site at the catalyst/electrolyte interface, it is electrochemically oxidized according to the following equation:

$$H_2 \dashrightarrow 2h^+ + 2e-$$

The electrons are transported through the external circuit, and the hydrogen ions are conducted to the cathode through the electrolyte, which is held in place by an inert inorganic or polymeric matrix.

Parenthetically, it should be made clear that the molten carbonate is not a reactant, is not consumed and does not pass out of the cells except in very small (trace) quantities in the cathode exhaust over a very long period of time (tens of thousands of hours of operation). Molten carbonate fuel cells (or DFCs) consume hydrogen, never need "recharging" and produce fresh water as a product along with the electrical power output.

2.1.1. Electro-Chemistry

A number of alternative fuel cell types have been studied in the past by AEL for the marine application. They include six different types with their sponsors for R&D. Over the last 30 years very little of the federal agency R&D support has been for the marine application. The vast majority of the federal agency R&D support has been for the space application, the

FIGURE 2-1 FUEL CELL CONCEPTUAL DIAGRAM

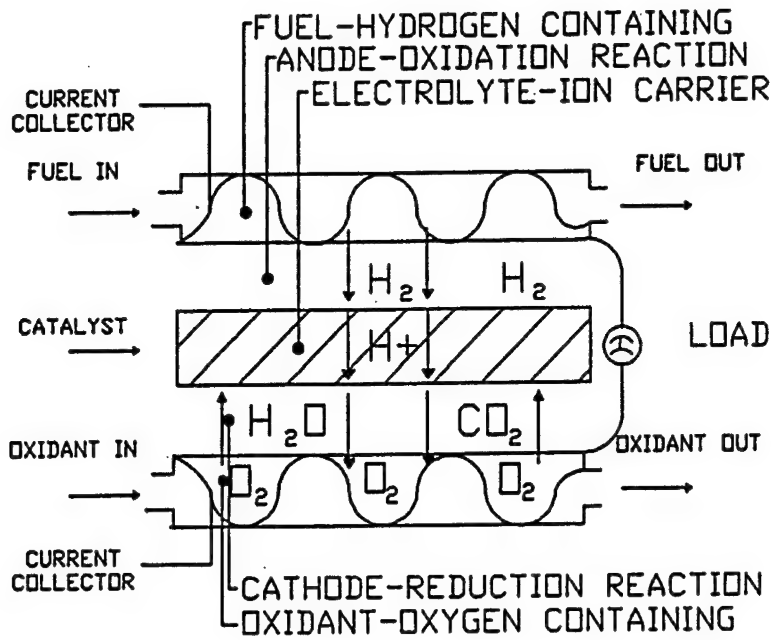
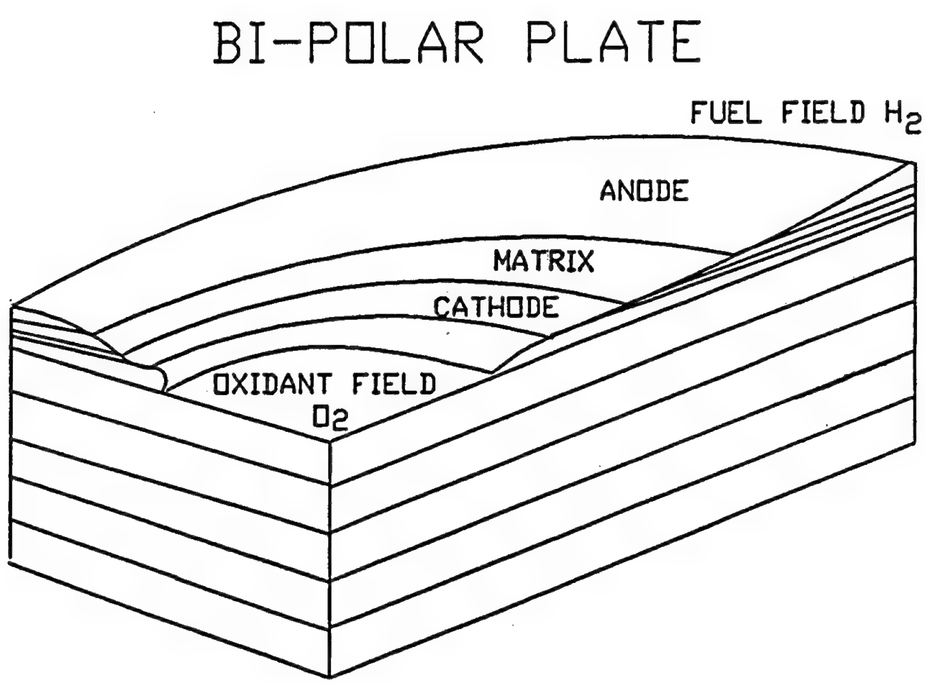


FIGURE 2-2 CUTAWAY OF STACK



terrestrial automotive/bus application and for the electric utility industry application. AEL has determined that the electric utility application types have the best chance of providing the marine/naval/maritime users with the needed power levels, the lowest cost per installed kW of power and the ability to utilize diesel or "distillate" type fuels[4,5,6,11]. The six types of fuel cells and their major sponsors are:

- Alkaline - NASA and NAVY.
- Proton Exchange Membrane (Solid Polymer Electrolyte) - NASA, NAVY, DARPA and DOE.
- Phosphoric Acid - ARMY, AIR FORCE, NASA, DOE, GRI and EPRI.
- Super Acids - DOE.
- Molten Carbonate - DOE, DARPA GRI and EPRI.
- Solid Oxides - DOE, DARPA AND EPRI.

Five of these six types are compared in Figure 2-3, in ascending order of temperature, from alkaline to solid oxide. The Super Acid types are still in the research status but are similar to the Phosphoric Acid type. Each was evaluated in 1987 under contract to the Navy according to a series of criteria developed by AEL. The criteria form the basis for selection of the most appropriate type for marine application based on the known attributes of each. The selection process used in the 1987 Navy sponsored study (Reference 4) is shown in Figure 2-4.

Alkaline fuel cells have long been used in the NASA manned space program in the Gemini, Apollo and Space Shuttle systems. The others have received varying degrees of federal agency plus Electric Power Research Institute (EPRI) and Gas Research Institute (GRI) research and development funding. In 1985/1986 the Office of Technology Assessment (OTA) of the U.S. Congress completed a Technical Memorandum (TM31) on the Marine Applications for Fuel Cell Development[3]. AEL's President instigated and later participated in the preparation of the Congressional OTA Report. That Report provided an excellent general treatment of fuel cells for both on-land and marine uses.

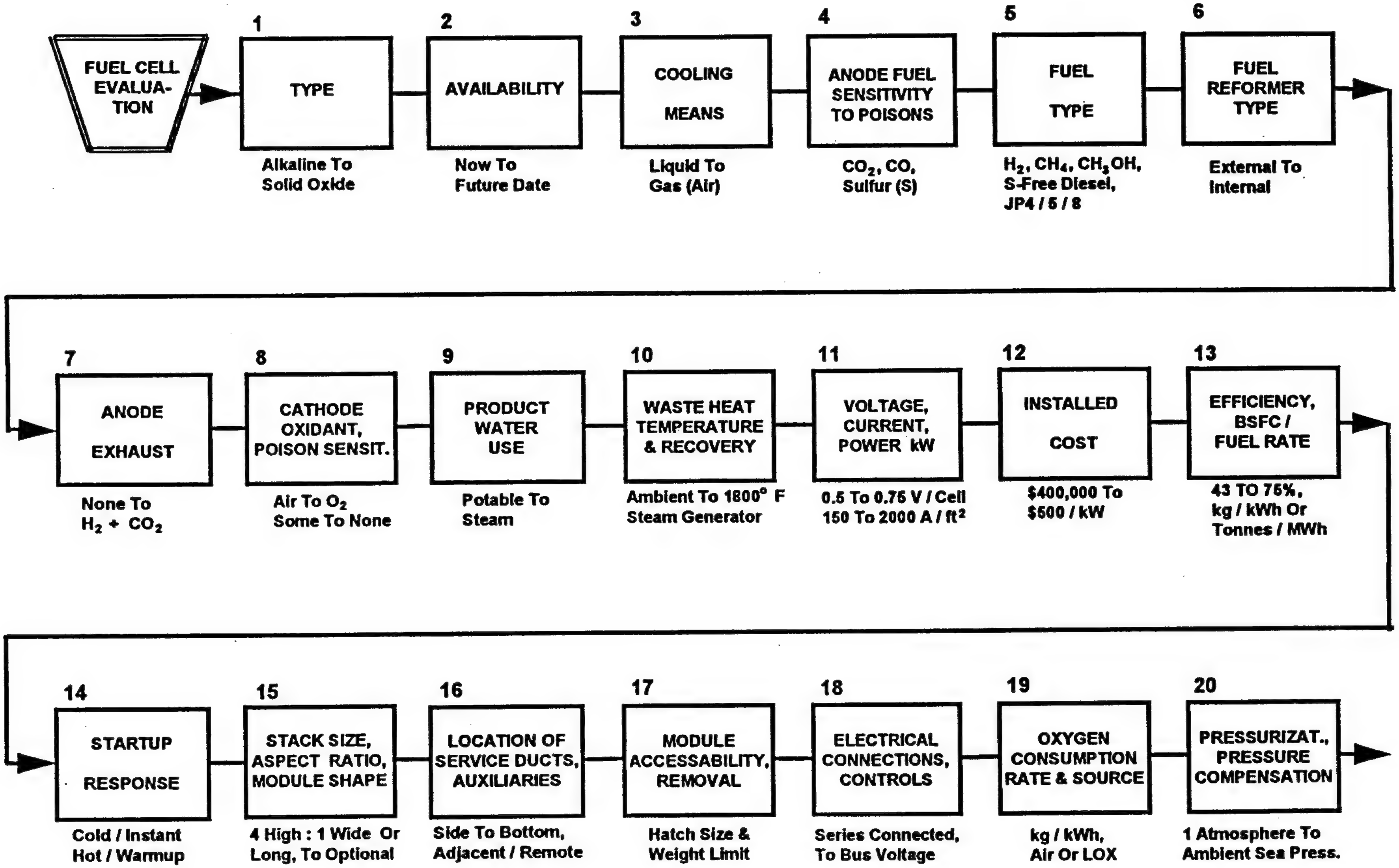
Figure 2-4 shows eighteen (18) steps in the process of selecting the most appropriate fuel cells for surface ship marine applications. Two (2) further steps in the process (19 and 20) are needed in order to arrive at the apropriate fuel cells for submarines. In submarines the oxidant must be available onboard when submerged. Also, the submerged operating regime permits the designer to take advantage of the pressurization of the fuel cell power system which can be provided due to ocean depth pressures. This aspect does not apply to surface ships.

Some key steps in the 18 step process are now discussed in summary form. Step No. 2, AVAILABILITY, involves the evaluation of the availability in the near furture of the fuel cells in the scale-up of size to that needed for ship service and propulsion power plants. Only the

FIGURE 2-3 PRINCIPAL TYPES OF FUEL CELLS

TYPES	APPLICATIONS	TEMP.
Alkaline	Spacecraft	212 ^{0} F
Proton Exchange Membrane	Spacecraft, Cars, Busses, Small Submarines	212 ^{0} F
Phosphoric Acid	Electric Utilities, Busses	375 ^{0} F
Molten Carbonate/ "Direct Fuel Cells"	Electric Utilities, Ships, Polar, Emergency Power	1,200 ^{0} F
Solid Oxide	Electric Utilities, Etc.	1,800 ^{0} F

FIGURE 2-4 MARINE- APPROPRIATE FUEL CELL PROCESS SELECTION



high temperature utility types (the PAFC, MCFC and SOFC) qualify because they have both the commercial cost driver function operable (driving down cost/kW) and the large power plant size ratings necessary. The INSTALLED COST (Step 12) is driven down fastest when the market size is the largest.

Step 5, FUEL TYPE, narrows the list of candidate types further. This is so because the operating temperature of PAFCs is too low to create either the needed heat for external fuel reformation or for the required steam-to-carbon ratios needed for the reformation of multi-carbon diesel type fuels, without burning some of the fuel to produce the necessary heat. Burning fuel for this purpose creates NO_x and drives down the energy conversion efficiency. Step 13, energy EFFICIENCY, BSFC/FUEL RATE are adversely affected for the PAFC, leaving only the MCFC and the SOFC types as serious contenders. Step 6, FUEL REFORMER TYPE, whether external or internal is the next criterion. External fuel reformation has been chosen by many MCFC development firms in Japan and Europe and by the US firm MC Power, Inc*. To externally reform there must be heat transfer surfaces in the fuel cell stack plus heat transfer ducts over to the reformer. In addition the reformate must be ducted back to the stack to feed the anodes. All these steps involve system complication, volume and weight. For a land-based electric utility installation, this may be acceptable.

AEL's evaluation of the Energy Research Corporation's (ERC) DFC* internal fuel reformation approach to MCFCs suggests that this technique is not only less complicated, it is more volume and weight conserving as well as being less costly. These are the factors which are of greatest importance for Steps 15, 16 and 17 with regard to MODULE SHAPE, LOCATION OF DUCTS and MODULE ACCESSIBILITY respectively.

The remaining aspect of the evaluation comes down to a choice between MCFCs and SOFCs (which also can internally reform the diesel type fuel). By admission of the DOE, EPRI and others the SOFC technology has lagged, and continues to lag, the MCFC technology by 7 to 10 years. The higher cost of the substantially higher operating temperature SOFCs needs to be traded off, hopefully, against some greater benefit, such as higher energy conversion efficiency which would reduce the long term fuel rate/BSFC and therefore fuel cost. Unfortunately, there does not appear to be any fuel rate improvement available for SOFCs. Indeed, some observers feel SOFCs will be slightly more fuel consumptive than MCFCs. Answers to these questions are still some years ahead.

Thus, from the above analysis, the current best choice is the MCFC, in the form of the ERC internal fuel reforming design called DFCs. The DFC design also incorporates an ERC patented means to take the Step 7, ANODE EXHAUST, which contains a small amount of unreacted H_2 plus CO_2, directly to the cathode inlets. Because MCFCs need CO_2 at the cathode along with O_2 this clever solution to the anode exhaust issue makes the ERC DFC more compact, lighter in weight, less costly and more fuel efficient.

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* "The US Government does not endorse products or manufacturers. Trade or manufacture names appear herein solely because they are considered essential to the educational objectives of this Report."

Therefore, the balance of this USCG Feasibility Study Report is based on the sophisticated ERC DFC design of mass produce-able MCFCs. The ERC second generation 9 ft^2 cells are used in the AEL advanced fuel cell plant one-sided-fit module design described in this Report.

2.1.2. COOLING METHOD

Fuel cells operate as an exothermal reaction requiring thermal management. The cooling methods used in the fuel cells can be liquid or gaseous. However, the liquid must not conduct electricity. This typically means demineralized fresh water or a dielectric liquid such as mineral oil. In the case of demineralized water the coolant is more difficult to control as temperatures approaches 212 degrees F, with the coolant existing in both liquid and gaseous phases. Thus the use of gas cooling, typically air, is common and provides lower system weight, no liquid leakage and ease of assembly of the fuel cell stacks. The DFC or molten carbonate type fuel cell has achieved the best thermal balance using this gas cooling process. The cooling process has been especially successful when the internal thermochemical reformation of the fuel can absorb a major portion of the electrochemical heat produced, providing the best heat balance as well as the simplest overall system.

2.1.3. ANODE FUEL SENSITIVITY

Many readily available carbonaceous fuels contain contaminants. The fuel cell types shown in Figure 2-3 vary from those with no tolerance (alkaline), to those with high tolerance for the most common fuel poison, sulfur. Other fuel contaminants include carbon dioxide (CO_2) and carbon monoxide (CO), both of which are formed in the thermo-chemical reformation of carbonaceous fuels to hydrogen (H_2) plus CO_2 and CO. The H_2 is the part fuel needed by the electrochemical fuel cells. Alkaline and proton exchange membrane fuel cells are permanently poisoned by carbon monoxide and alkaline fuel cells are poisoned by carbon dioxide. Thus these two fuel cell types are not readily fed from reformed hydrocarbon fuels. Proton exchange membrane fuel cells can be used with reformed sulfur-free fuels such as methanol so long as great care is taken to chemically shift all the carbon monoxide over to carbon dioxide. The phosphoric acid and super acids fuel cells have complete carbon dioxide tolerance and a degree of carbon monoxide tolerance.

Molten carbonate fuel cells consume CO. Thus they operate without any carbon monoxide tolerance problems. However, they are still affected by sulfur. Only the extremely high temperature solid oxide type has some sulfur tolerance. It must always be remembered that a sulfur-tolerant solid oxide type fuel cell will produce the atmospheric pollutant SO_x, which is very undesirable. This effectively means that whatever fuel is contemplated for use in fuel cells by the U.S. Coast Guard or any other ship owner/operator must be sulfur-free (less than 1 PPM). The removal of sulfur from diesel fuel onboard ship has been considered in an AEL Study[12] done in 1994.

2.1.4. FUEL SPECIFICATION

The sulfur-free fuels in descending order on the chart are pure hydrogen only for the alkaline fuel cells, through hydrogen or methanol for proton exchange membrane, to hydrogen, methanol, natural gas and sulfur-free diesel for phosphoric acid, super acids and molten carbonate. The relative sulfur tolerance of the very high temperature solid oxide type makes it (prospectively) the only type which might be able to use ordinary sulfurous diesel fuel, JP5 or JP8. However, the use of a sulfurous fuel necessarily means the production of air polluting SO_X in the exhaust. Thus, to eliminate SO_X air pollution the obvious answer is to remove the S (sulfur) from the fuel. This sulfur removal step is a relatively routine oil refinery process. That is where it should be done and already is where it is being done.

Diesel fuel as the preferred logistics fuel for USCG operations has all the desired characteristics such as high heating value, i.e. BTU/lb, satisfactorily high flash point, high viscosity and usability in many of the existing facilities. Administrative changes in the Federal Fuel Supply specifications for a special diesel fuel that would lower the sulfur content to less than 1 part per million would result in very small increase in the cost of the fuel. This is due in part because as new refinery facilities are being built to make various clean fuels, the refinery process has been changed to include hydro-desulfurization of the incoming crude oil as the first step before the catalytic cracking processing. The refinery catalytic processes are poisoned in the same way fuel cells catalytic processes are poisoned. Therefore sulfur poisoning should not be allowed to occur in the newer fuel refinery processing facilities. The sulfur in the existing diesel fuel is detrimental to the environment, corrodes the machinery exhaust systems and thus reduces power plant equipment operational life.

2.1.5. FUEL REFORMATION

With the exception of the alkaline fuel cell type, which must use pure hydrogen fuel, all the others can use a reformed fuel. Reformation is an endothermal process, which produces hydrogen for consumption in these other types of fuel cells. Using an external reformer for the endothermal reaction is less efficient than causing the same process to occur internal to the molten carbonate fuel cell stack. The big system-level advantage of the molten carbonate fuel cells is that they can internally reform desulfurized diesel fuel with high efficiency, at 1,200 degrees F. The high quality waste heat can be used to produce more electric power or it can also be used for other purposes such as space heating or desalinator heating. Solid oxide fuel cells, which operate at 1,800 degrees F, have the same internal reformation advantages as the molten carbonate, but are further in the future. They remain more expensive because of higher materials costs and because they have not as yet entered the commercial demonstration phase of multi-magawatt power plants.

The molten carbonate fuel cell type has a demonstrated efficiency of 55%, before waste heat and byproducts are considered. The higher heating value of the fuel is 18,900 BTU/lb using sulfur-free diesel fuel. This is the most economical high heat value fuel available that is compatible with existing U.S. Coast Guard ship fuel systems. The Brake Specific Fuel Consumption (BSFC) is 0.18 pounds per horsepower hour (lb/HPh) at greater than 30% load.

In metric terms this is 0.128 kg/kWh. The other fuel cell types are not expected to perform in the same range and because of system cost and other evaluation factors referred to above are not considered appropriate for use by U.S. Coast Guard at this time.

2.1.6. ANODE EXHAUST

In the case of the alkaline fuel cell there is no anode exhaust because all the pure hydrogen is consumed in making water and electricity.

In the proton exchange membrane, phosphoric acid and super acid fuel cells there will be some unreacted hydrogen and carbon dioxide in the anode exhaust. In the solid oxide fuel cells the product water, in the form of steam, is formed at the anodes and therefore exits via the anode exhaust manifold along with some unused hydrogen and carbon dioxide.

In the DFC molten carbonate type cells some carbon dioxide is present in the anode exhaust. This carbon dioxide is then directly fed to the cathodes along with the incoming air because the DFCs are carbonate devices and work best with the higher carbon dioxide levels.

2.1.7. CATHODE OXIDANT

The only oxidant acceptable to alkaline fuel cells is pure oxygen. The proton exchange membrane, phosphoric acid and super acids fuel cells can all operate from air or oxygen. Standard filtration of the ambient air is necessary to remove salt spray and particulate contamination. It is accomplished with preheaters, filters and demisters typical of gas turbine intakes for other U.S. Coast Guard vessels. The oxidant requirements of the two high temperature fuel cell types, molten carbonate and solid oxide, are readily met with ambient air.

2.1.8. PRODUCT WATER PRODUCTION

All fuel cells produce fresh water. In alkaline and proton exchange membrane fuel cells (PEMFCs) the product water is in liquid form. Steam must not be produced so a carefully controlled water management system is required with these two types. In ascending order of operating temperature the water produced in all the other fuel cell stack types will be in the form of steam. The heat carried in the super heated steam from the two high temperature fuel cell types (molten carbonate and solid oxide) can be used to operate other auxiliaries or produce more electricity. Once the steam is condensed, the potable water is available for consumption. Significant quantities of nitrogen and carbon dioxide (CO_2) are also present in the exhaust stream from the cathodes of molten carbonate fuel cells.

2.1.9. WASTE HEAT

As has been previously explained, the molten carbonate and solid oxide fuel cells provide a substantial quantity of high quality waste heat. Removal can be by the use of air, demineralized fresh water or a dielectric liquid such as mineral oil. Air cooling provides the lowest weight and best thermal integration per installed kW of fuel cell power plant. A simple

straightforward heat recovery means to turn waste heat into DC electricity is to use a series of Peltier Effect thermoelectric modules on the exhaust manifolds. Conventional means using a steam working fluid and a gas turbine generator can also be used, to produce AC or DC electricity.

2.1.10. POWER DENSITY

Amperes per square foot (Amps/ft^2 or abbreviated as "ASF") and cell voltage define the power output possible from typical fuel cell stacks. For the proton exchange membrane type, recent work by the manufacturers have demonstrated substantial increases in the current capacity in Amps/ft^2 when operated with pure hydrogen fuel and pressurized to 6 Atm (Atmospheres) or 90 PSI (pounds/square inch) pressure. Values of 2,000 Amps/ft^2 represent significantly higher, by a factor of ten, current capacity than that of phosphoric acid or molten carbonate fuel cells. The cell voltage is lower for the proton exchange membrane type, at 0.5 volts as compared with 0.6 for phosphoric acid or 0.75 for molten carbonate. The current capacity factor still dominates in the calculation of the power output of a typical stack per unit volume or weight. These considerations would, if economic factors were not the major driver, make the proton exchange membrane type attractive for weight limited systems.

The disadvantages of a high current density in "high power" PEMFCs i.e. 100 kW and up, is the difficulty of maintaining the stack water balance. The PEMFC designer cannot permit the waste heat to produce steam at the cell level because the membranes will be damaged and rupture will result. Power surges or rapid load changes would instantaneously be followed heat surges which will produce steam. This dynamic response "thermal runaway" difficulty with PEMFCs is a serious flaw in their application to traction type uses such as ship propulsion.

The ship application of fuel cell power plants is not "weight limited" ("volume-limited" conditions apply in most ship designs). For the foreseeable future the much lower cost of the molten carbonate fuel cell type makes it more attractive.

MCFCs and particularly internally reforming direct fuel cells (DFCs) have superior throttle response because of the intimate thermal contact between the exothermal cells and the endothermal fuel reforming function carried out within the stack.

2.1.11. COST PER KW

Acquisition cost is customarily described in terms of \$/kW installed for the modules, which includes the cost of auxiliaries or balance-of-plant (i.e. air handling, inverters, control and fuel service system, etc.). Acquisition cost for molten carbonate fuel stacks in mass production are expected to be between \$500-1,000 per kW i.e. \$0.50-\$1.00/Watt in 1996 dollars. Balance-of-plant costs will initially raise the cost per kW to between \$1,000-1,500 per kW in 1996 dollars. Lower prices for DFCs will occur as more orders are received by Energy Research Corporation (ERC), of Danbury, Connecticut. The "second generation" 9 ft^2 cell sized stacks are now being built in small quantities. Additional orders are expected to follow as the pilot

manufacturing facility, the Fuel Cell Manufacturing Corporation (FCMC), a subsidiary of ERC, is placed online and cost targets are confirmed. For the record the first 6 ft^2 cell sized 125 kW 12 ft tall stacks were shipped from the Torrington, CT, FCMC plant in December 1991.

2.1.12. STACK FORM FACTOR

The stack height, size (footprint and volume), aspect ratio and module shape are driven by the available space plus the corresponding cell current density and cell thickness or height. The molten carbonate direct fuel cell (DFC) current density is 160 Amps/ft^2. This is multiplied by the stack effective area of 92% and cell height of 0.333 inches per cell. Currently FCMC is fabricating 2.25 foot X 4 foot (9 ft^2) cell stacks. This has been used as the cell size in a 6 ft tall stack to configure the AEL designed marine ship application module shape. The module shape is discussed later.

The above process now permits a calculation of the module's power output. At the available 6 foot (72 inches) stack height based on 0.75 volts per cell, a cell height of 0.333 inches, there will be a maximum of 216 cells, which will in turn produce 162 Volts. The net stack output is calculated as follows: Current density of 160 ASF x 9 ft^2 x 0.92% cell active area factor x 162 Volts / 1,000 Watts = 214.6 kW or 215 kW.

This is substantially more than the previously assumed nominal 6 ft tall stack output of 180 kW. This power output aspect is discussed further in Section 2.2.1.1.

2.1.13. STARTUP AND RESPONSE

Startup response is especially important if the system is required for emergency applications or instantaneous load following from a cold start. Molten carbonate fuel cells must be at a temperature of at least 1,000 degrees F so that the electrochemical carbonate mixture becomes active. Unless specific maintenance is underway on a module or if it is not in use at all it should be held in hot standby by circulating dry nitrogen and carbon dioxide gas derived from the cathode effluent of the loaded module stacks. The cathode exhaust contains water vapor, CO_2 and the balance of the air (mostly nitrogen). As the water vapor is condensed out, there is a ready supply of this dry nitrogen and carbon dioxide gas available. It is then re-heated and fed to the cathode inlet manifolds of the "hot standby" fuel cell module(s)

For the start up from "dead cold" MCFC/DFC stacks can be warmed up to operating temperature by using auxiliary Power Units (APUs or small gas turbines) using the sulfur-free diesel fuel. Effluent gas temperatures from these APU devices can reach 1,500 degrees F. APUs are already available in the U.S. Coast Guard because they are used to start military aircraft and helicopters.

The molten carbonate fuel cell stacks follow major load changes well. The most likely limiting factor will be the response of the AC invertor response for ship service loads and the mechanical inertia reponse of the ship propellers. During the preliminary design a dynamic

analysis will need to be carried out to confirm the transient electrical characteristics of the Fuel Cell Power System. If applications exist where high quality power is necessary such as precise 60 Hz sine wave AC, more precise inverters or rotating frequency converters can be used. This is no different from current marine diesel generator systems in which a major change in load requires some time to respond in voltage, frequency and power.

2.1.14. SERVICE LIFE AND MTBF

The molten carbonate/DFC power modules for use aboard vessels are expected to have long service life by selecting subcomponents that match the stack expected full power MTBF of 58,000 hours. This interval is enough service life, for example, to circle the planet at sea 29 times at full speed for the USCG VINDICATOR. The critical subcomponents are expected to be the power inverter, control system, pumps and fan motors. Internal stack seals appear to be the key service life-limiting item. Once more experience is gained it will, confidently, be possible to extend stack service life well above 58,000 hour MTBF. Diesel and gas turbines have MTBFs of approximately 5,000 and 12,000 hour respectively. It is recommended that these DFC power modules be placed on-service and to only remove them upon failure. The optimum time for a change-out to a new module would be chosen to take advantage of improved fuel cell's with higher power density. Each subsequent generation module will have improved technologies built-in to enhance performance and reduce cost.

2.2. Modular Configuration

The molten carbonate fuel cell power modules envisioned for the VINDICATOR repowering will be 42 inches wide, 96 inches long and 84 inches high. The ship service AC power is provided by static inverters. These inverters may convert the nominal 160 Volt DC bus voltage from one or more fuel cell modules to three phase 440 Volts AC. A number of fuel cell module DC outputs are combined in series to produce the 800 Volts DC for the propulsion motors. 5 modules x 160 Volts = 800 Volts. The 60 Hz AC ship service power inversion will be done using off-the-shelf inverter components.

The control of the fuel cell power system is expected to be accomplished using a realtime expert system, which integrates and monitors all the subsystems. The type of control system envisioned could be a GENSYM (General Simulation Corporation) G2 offline compiled application which could be modified for special applications to coordinate other shipboard type sources of power from the emergency generator.

The fuel service subsystem could consist of a small day tank and metering pump. A contaminated fuel alarm could be hardwired in the power system to allow module shutdown in the case of fuel purity problems. This subsystem would be semi-independent of the power control system in that the control system may activate a fuel stop condition using the same circuit for an individual fuel cell module. The power control system would have a main fuel stop circuit to halt the fuel flow to all the fuel cell modules in the event of a plant-wide shut down command.

2.2.1. STACK PARAMETERS

The DFC subsystems are better understood when viewed as a Block Diagram such as Figure 2-5. Drawing from extensive experience in marine industry practices, which yield efficient use of space and integration of the required maintenance access, the modules have been configured to be largely autonomous in their operation.

The Block Diagram shows the components within the one-sided-fit fuel cell module (within the heavy black border line as shown). The balance-of-plant (BOP) shows the associated ancillary components of a fuel cell power system. The BOP would be designed to support significant numbers of modules. This would be 12 in the case of the 2.4 MW power plant needed for the T-AGOS ship VINDICATOR. The design of the fuel cell stack, shown in the center of the Module in the Block Diagram, is intended to provide a significant power output consistent with a stack height limitation of 6 ft. When the stack is enclosed in the Module's cover the overall height of the unit is 7 ft. When the ERC "second generation" electric utility-type 9 ft^2 cells are used the 6 ft tall stack will have 216 cells in it.

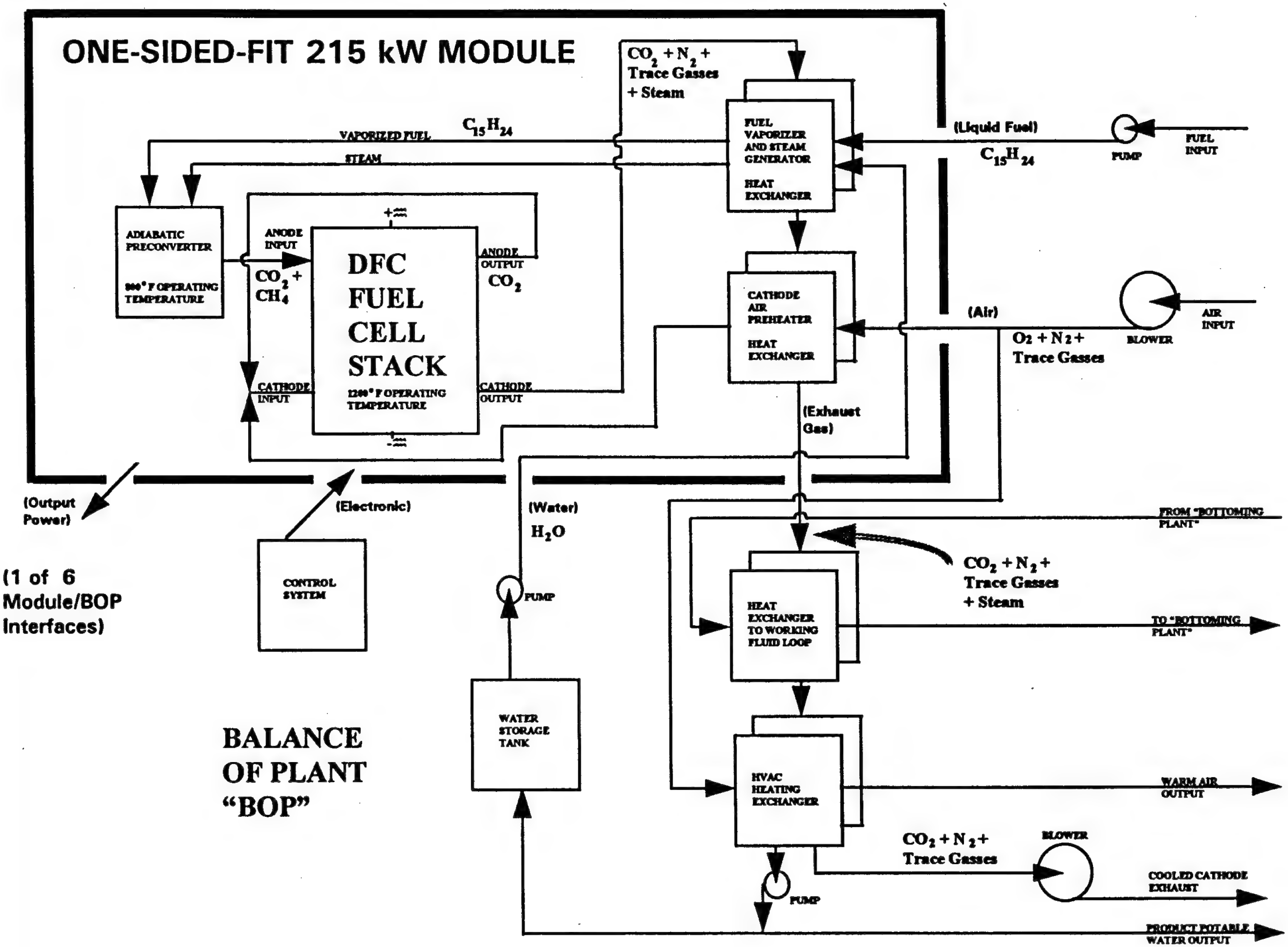
As shown in the Block Diagram the diesel fuel and the water enter the module as liquids. They are vaporized by heat transfer from the cathode exhaust in the upper heat exchanger shown. The vaporized fuel and steam enter the Adiabatic Preconverter, a vertical right circular cylinder, and exit in a single larger pipe over to the anode inlet manifold. The anode inlet manifold feeds the 216 anodes in the cells with a mixture of CO_2 and CH_4. The purpose of the adiabatic preconverter is to assure that all of the carbon in the diesel type fuel is bound to a single-carbon molecule of CO_2 or of CH_4. No free carbon (soot) is emitted by the adiabatic process described. The CH_4 fuel is what the 9 ft^2 electric utility DFC fuel cells are designed to internally reform. The result of that process, at the anode outlet, is overwhelmingly CO_2 and a small percentage of H_2. The anode output is fed to the cathode input. This H_2 is then electrochemically reacted in each cell with Oxygen (O_2) from air at the cathodes to produce the DC electric power output and the product potable water.

Air is provided to each module through a square duct opening in the module's mounting base and is heated up to the fuel cell stack's operating temperature by the lower heat exchanger shown in the Block Diagram. The cathode outlet is mostly nitrogen (N_2), steam and CO_2. The exhaust gas from each cell cathode is used to provide the heat to warm up the incoming reactants and air, as was explained above. The product water is condensed out of the cathode's exhaust flow by the BOP heat exchangers which are outside the module, as shown in the lower part of the Block Diagram.

The nominal 160 Volt DC output comes from the stack's base electrical connection and the stack's top electrical connection, through a heavy duty insulated connector through the module's base plate. The amperage flowing through these connections will be on the order of 1,400 Amps per module.

Details on the fuel cell module's physical configuration are covered subsequently and in Appendix A.

FIGURE 2-5 DFC MARINE POWER PLANT BLOCK DIAGRAM



2.2.1.1. DFC Sizing and Calculations

<u>ASSUMPTIONS</u>

Current density = 160 Amps/ft^2; Volts = 0.75 volts/cell; Molten carbonate cell height = 0.333 inches/cell with 2.25 ft by 4 ft (9ft^2) cell area.

I. <u>VOLTAGE</u> - One hundred sixty-two (162) Volts/0.75 V/cell = 216 cells. 216 cells, for a height of 72 inches tall stack.

II. <u>POWER</u> - Current density = 160 Amps/ft^2 X 9ft^2 x 92% active area factor per cell = 1,324.8 Amps. Power = 162 Volts X 1,324.8 Amps = 214.6 kW or 215 kW. Twelve modules will provide about 2.575 mega-watts (MW) of power. Four rows of 3 stacks would therefore provide the needed ship power of 2.4 MW. 5 stacks connected in series will provide 800 Volts DC.

III. <u>DIMENSIONS</u> - The Module is 3.5 ft wide, 8 ft long and 7 ft tall. It has all the services coming through the base plate.

IV. <u>MODULE WEIGHT</u> - The stack, heat exchangers, adiabatic converter, control system, air handling, fuel service and other auxiliary systems including structure and insulation weigh approximately 14,900 pounds. This self contained unit is capable of independent operation or integration into a grid system as shown in the ship arrangement drawings.

V. <u>FUEL RATE</u> - Total consumption in lbs/kWh is based on an assumed energy conversion efficiency of 54%. No heat recovery or potable water energy credit is included in this efficiency number.

$$= \frac{3{,}413 \text{ kwh}}{\text{Eff X LHV(diesel fuel)}} = \frac{3{,}413 \text{ kwh}}{0.54 \text{ X } 18{,}900 \text{ BTU/lbs.}}$$

= 0.33 lbs/kWh, or 330 lbs/h for 1MWh

330 lbs/h = 46.5 gals/h for 1 MW of power (Based on 7.1 lbs/gal)

2.575 MW will require 46.5 gals/h x 2.575 = 119.7 gal/h fuel consumption at full power. At 2.4 MW output power the fuel consumption will be 111.6 gallons per hour. Based on this figure the volume of fuel storage can be calculated.

VI. <u>VOLUME OF FUEL STORAGE</u> - Volume = 111.6 gallons per hour X 24 Hours / 7.1 pounds per gallon X 50.85 pounds per cubic foot = 19,183 cubic foot service tank. A Storage tank volume of 19,183 cubic feet = 20,000 cubic feet or about a 136,000 gallon day tank for the modular fuel cell power plant room.

2.2.2. MODULAR INTERFACE TO PLATFORM

The fuel cell modules and their associated auxiliary equipment will be located in the main "machinery space". The modules will be arranged in four rows (fore-aft) with three modules athwartships to allow for twelve module sites. The length and width of the space is approximately twenty feet four inches by thirty four feet respectively. The one-sided-fit provides for a simple installation and removal by trained personnel. Rigging the modules in place can be accomplished by overhead tracks. The ducts and piping required to handle the service fluids (both gaseous and liquid), flow under the deck structure along the longitudinal axis allowing the best arrangement for groups of fuel cell modules and easy connection of each module to services/output connections. This arrangement permits bottom connection of these services as well as for the generated power electrical, monitoring and control instrumentation connections. Greater detail concerning the module configuration is found in Appendix A, where figures show the module and its subsystems.

2.2.3. STRUCTURE

The former diesel engine generator machinery space will first have the four diesel engine generators removed. Then the sound isolation "bedplates" are removed down to the "tank top" level. The various grating deck passageways between the four diesel engine positions are removed as well as most of the 4 diesel generators' balance of plant. These items include water jacket heat removal manifolds and heat exchangers which are located below the grating deck and fixed to the tank top.

In place of this a new reinforced deck/false floor is added (and tied down to the tank top) to provide the surface onto which the fuel cell modules will be placed. The Figures and descriptive text in Section 3.8 <u>Machinery Box Layout</u> describe this new layout and the logic of the approach from the modular one-sided-fit fuel cell power plant point of view. The 3/4 inch module hold down rods (4 per module as shown in Appendix A) will take full military loads without tearout or lateral permanent deformation. These structural considerations will be the subject of a preliminary design structural modeling task in the next stage of the program.

2.2.4. ELECTRICAL INTERFACES

The power system is designed to operate without a load center for small remote sites using DC loads, providing a limited mix of both AC and full range of DC load services up to the limits of the module or groups of modules in operation. The shipboard load center will allow connection through bus and protective devices as required to serve up to 600 kW AC service. This implies three (3) 200 kW 440 VAC, three phase inverters to service ship board loads. The propulsion DC switchgear would largely remain in place. Specially sized switching devices are required for each new power source, including fuel cells. It is not a significant development item because numerous DC electric drive systems are available. This item will be the subject of a preliminary design study task. The fuel cell modules are designed to operate autonomously or under control from a central station.

2.2.5. AIR HANDLING INTERFACES

The ambient oxygen consumption rate varies based on the load and cooling demand. A nominal 215 kW stack at idle will require 20 CFM and at full load will require on the order of 420 CFM for the mix of oxidant and cooling air. Ambient air from outside the space in an emergency or normally from the intakes must be preheated on the way to and within the modules prior to introduction to the fuel cell cathode manifold. Preheating of air will be accomplished through a separate BOP air-to-air heat exchanger. This heat exchanger can be used to extract or condense the potable water from the cathode effluent gas stream. This effluent carbon dioxide and nitrogen gas stream can be used via a gas-to-gas heat exchanger to supply space heat for the fuel cell power plant room or to living spaces.

2.2.6. CATHODE AIR SYSTEM

A module air handling system could provide positive pressure to the cathodes in concert with the aspirated exhaust system in the stack, as discussed below. This would allow redundancy, safety and graceful degradation in the case of an air handling system failure. The cathode air system would be rated at 450 CFM. Selection of the best alternative will be the result of a trade-off during the preliminary design. The aspirated exhaust would be capable of moving a total 7,000 CFM of air up the exhaust stack.

2.2.7. EXHAUST SYSTEM

Waste heat will be produced at the rate of about 30 percent of available heat from the fuel. Recovery of this heat for space heating and distilled water production is achieved using air-to-air heat exchange in the cathode exhaust gas stream. Air flow is three times the flow necessary for the cathode oxygen reaction to occur or about 5880 (420 per module) CFM for twelve modules at full load and full propulsion power. Approximately 2,736,000 BTUs per hour would be produced at full power output. The DFC power plants can silently offer a great deal of space heating for the nearby spaces.

2.2.8. FUEL HANDLING INTERFACES

The results of the AEL test program conducted for the U.S. Navy confirms that molten carbonate DFCs modules are capable of using a wide variety of carbonaceous, sulfur-free fuels (Natural gas to sulfur-free diesel type fuel). This is achieved with only a minimum reduction in thermal efficiency when changing between different fuels. This means that DFCs are well suited to the changing availability of fuels. The USCG has used marine diesel fuels, F-76, JP-8, JP-4, gasoline, as well as other aromatic hydrocarbons for fuel in the past. Molten carbonate DFCs have a proven multi-fuel capability. This may become important to the USCG in the future as new fuels are made available and should conventional fuel types become scarce.

The DFC fuel supply system would use DC motor driven pumps. Via a fuel piping

distribution system each module receives fuel. In each module the fuel is heated to vapor, along with water heated to steam, initiating the first step in adiabatic processing of the sulfur-free diesel fuel into synthetic methane in the presence of steam and the nickel catalyst. The fuel system is hard wired to the idle flow rate so that in the case of control system failure the system will drop to the idle condition. Manual features will allow emergency operation by hand adjusting the throttle. The realtime expert system will schedule the fuel system for operation between 25 percent throttle and full load. This will allow for the best load following and safest operation. The fire stop system as well as manual stop valves for the fuel will allow automatic or emergency manual shutdown of the system. A fuel transfer and fill system to each fuel cell module allows the replenishment from the "fuel cell room" day tank. The fuel cell room day tank will be replenished from the fuel oil storage system. Fuel piping from the fuel cell room day tank will be to each module's piping interface which is located opposite the stack end of the module at the base connection from the foundation piping.

2.2.9. PRODUCT WATER INTERFACES

The product water system is a single pass condenser by which the cathode exhaust is cooled down to the temperature at which the water condenses out. The condenser is probably not a direct air-to-air heat exchanger, but a plate type, cross flow condenser. The resulting potable water must be treated with ozone, bromine or chlorine before storage in the potable water storage system tank. This step is the same as that currently required for shipboard distillers or flash type evaporators to ensure the pure water does become contaminated with bacteria.

Water production from the fuel cells' electrochemical reaction is at the rate of approximately one gallon of pure water per gallon of fuel consumed. Using a 90 percent recovery factor, 2.4 MW of DFC power plants is capable of producing approximately 2,400 gallons of potable water per day (GPD). This water is of high quality and is in addition to the waste heat that may be used to increase the present onboard evaporator capability of 3,000 GPD.

2.2.10. MODULE FUEL TREATMENT SYSTEM

DFC internal reformation is the most important aspect of the molten carbonate fuel cell approach. Thermal integration is the most effective means to produce hydrogen as well as to heat and cool the fuel cell stack. This process significantly reduces the complexity of the fuel reforming, cooling and control subsystems. Safety of the overall system is enhanced because no "hydrogen streams" are required. The steam reformation occurs "onsite" in the stack where the hydrogen is then electrochemically consumed. The cell's electrochemical reaction, in effect, "pulls" the needed hydrogen from the reformer based on electrical demand. The heat included in the process is a secondary factor because the cooling air and oxidant feed stream are the same, so that as demand for oxidant is supplied the cooling is also supplied. More waste heat is then available for ship service needs from the BOP cooled effluent or it may be put up the ship exhaust stack.

2.2.11. CONTROL SYSTEM INTERFACES

The DFC control system is expected to be a hybrid system. The first part of the system will be a hard-wired startup to steady-state idle at 25% rated output and allow manual control of fuel and air systems. The second will be a realtime expert system capable of independent operation from standby to full rated power. The system will have the capability to automatically respond to changes in demand, casualties and load leveling logic for best fuel economy. The system will provide status, advisory, custom advisory and alarm conditions locally or remotely. Unattended operation can be programmed, if supporting systems are brought under the control of the realtime expert system.

The DFC control system shall provide information on the following systems or components:

- Direct Fuel Cell (DFC) stack temperatures, output voltage and current at each stack, stack pressure, airflows and O_2, H_2, water vapor and CO_2 content.

- DFC air system to include APU status, RPM, temperature and output airflow, air blower temperature, output in CFM and status, diverter valve status, temperature and position, preheated airflow and ambient air temperature.

- DFC inverter system and power conditioning temperature, DC voltage and current, AC voltage and current, frequency, phase angle and cooling fan status. In addition, load demand for both AC and DC will be available.

- DFC fuel system day tank level, fuel pump status, flow rate, demand rate and temperature and atomizer pressure.

- DFC heating system air flow in CFM, effluent air temperature and secondary air temperature.

- DFC potable water system temperature and flow rate in gallons per minute (GPM). Air to air heat exchanger flow, process steam temperature and pressure, cooling air pressure and air pump status.

- Carbon dioxide and hydrogen extractor temperature, flow rates and status.

- Emergency fire detection and halon system to include infrared, fixed temperature and rate of rise temperature sensors for each module.

2.2.12. MODULE WEIGHT AND CG

The module weight has been very conservatively estimated as 14,900 pounds for the purpose of this feasibility study. The preliminary design stage will permit this estimate to be refined. The space and weight analysis for the fuel cell power system is found Section 4.3.

2.2.13. MODULE POWER DENSITY

As has been shown above DFC power plants are more efficient than any heat engine driven electrical power plant. This energy conversion efficiency is true at full power and is even more substantial if the comparison is made at idle and at part throttle conditions. In the specific case of diesel generator power plants this difference can be determined by comparing typical performance parameters such as brake specific fuel consumption (BSFC) and/or the energy conversion efficiency. When the additional information is available as to the long term i.e. a full year, the percent of the time at various throttle settings can be factored into the long term BSFC. The typical BSFC for the DFC without any heat recovery and with no potable water energy credit is 0.33 lbs/kWh as compared with 0.55 lbs/kWh for a current Caterpillar diesel generator system fitted to the USCG VINDICATOR when fully loaded. These BSFC values correspond respectively to full power systems efficiencies of 54 and 33 percent respectively.

2.2.14. MODULE PHYSICAL DIMENSIONS

The module physical dimensions have been confirmed using computer aided design analysis of the individual components and connecting parts. Details are found in Appendix A.

2.2.15. MODULE OPERATING PARAMETERS

The fuel cell module operating parameters are described in detail in Section 4.2.

2.2.16. MODULE STARTUP

The start up sequence for the module from "cold iron" is as follows. The engine room day tank is filled from storage tanks that have been tested for fuel oil purity and is tested upon fill for sulfur content. The day tank service system is secured and the module fuel header is pressurized. The control system is initiated and begins the process of sensing module conditions. The fuel oil day tank heaters should function to keep the fuel oil between 70 and 90 degrees F. At power on to the module the cathode air system will run up to 25% load.

The DFC air handling system is composed of three major components, the variable speed air blower, the auxiliary power unit (APU) and the diverter valve system to control preheat and startup. The DFC Air System is feed by a 24 volt battery to start the APU and bring the variable speed air blower up to speed. The APU provides the energy in the form of a hot gas stream to heat the DFC stack to its operating temperature. This is accomplished by shunting ambient air to the stack cathodes mixed with 1,500 degree F APU effluent. This controls the thermal expansion of the stack and controls the startup of the reformation process. The water introduced will heat to steam and as the stack approaches 800 degrees F fuel will be supplied by the fuel metering pump and atomizer. The DFC air system will shut down the APU when the stack output has supplied enough voltage and current to provide for the air blower, the fuel metering pump and atomizer, 24 VDC charging system and the control system. The battery system will then be placed on charge. The APU will spin down after its fuel mixture is

cut. The air blower is capable of supplying 20 to 250 cubic feet per minute (CFM), depending on the load or cooling demand. The ship service exhaust ducts are aspirated to allow flows above the rating of the on module exhaust fan at full power with a 10% margin. This is also a safety precaution to keep the engine room under negative pressure, thus assuring that all exhaust leaves the ship environment before mixing. The exhaust is low in oxygen and could cause a problem for personnel in confined spaces such as the engine room. This is the same as the design for gas turbines. Preheated air is available from the cathode exhaust air-to-air condenser used to make the product water. The aspirated air flow will be capable of operating individual module at full power should a module based cathode supply air system fail during operation.

With VDC low and stack temperature low and all other module conditions normal the control system in "auto start" will initiate the start sequence for the APU and after the diverter valve indicates fully shut. The APU will run up to normal run condition and the control system will start a one minute time and APU exhaust temperature normal (1,400 degrees F). The diverter valve will open on control system command and the module air handling system will schedule make up air to stabilize the stack at 1,200 degrees F. This process should occur in about 10 minutes time and is the subject of a module bench test during the 215 kW module proof-of-concept testing. The control system opens the module water make up valve and then the fuel valve to the injector so that a normal idle condition can occur in the stack. The control system will sense VDC normal for idle condition at 160 VDC and close the diverter valve and then initiate a stop to the APU once the diverter valve is fully closed. The control system then auto parallels the module to the DC bus and commands the air and fuel flow rates to follow the load as necessary.

2.2.17. MODULE SHUTDOWN

The control system would schedule the air and fuel flow to the idle condition and monitor the stack and BOP equipment temperatures until the module is within the parameter for a normal stop. The control system would then open the bus tie to the module and initiate a normal stop sequence which is: fuel flow off, water flow off and air handling system to cool down/standby.

2.2.18. MODULE QUICK-START

The start up sequence for a single module quick-start from "cold iron" is as follows. At power on to the module the cathode air system will run up to 75% load flow. With VDC low and stack temperature low and all other module conditions normal the control system in auto quick start will initiate the start sequence for the APU and after the diverter valve indicates fully shut. The APU will run up to normal run condition and the control system will start a 15 second timer and APU exhaust temperature normal (1,500 degrees F). The diverter valve will open on control system command and the module air handling system will schedule make up air to stabilize the stack at 1,150 degrees F. This process should occur in about 2 minutes time and will be the subject of a module bench test during the 215 kW module proof of concept testing. The control system opens the module water make up valve, and then the fuel valve 60 seconds later to the injector so that a normal idle condition can occur in the stack.

The control system will sense VDC normal for idle condition at 160 VDC and close the diverter valve and then initiate a stop to the APU once the diverter valve is fully closed. The control system then auto parallels the module to the DC bus and commands the air and fuel flow rates to follow the load as necessary.

2.2.19. MODULE NORMAL OPERATION

The module normal operation will be under fully automatic control. This include electric plant management with all in service modules in hot standby to be added or taken off line by the control system depending on electric load demand and propulsion load demand. Each module will have protective functions to guard against common casualties such as fire, module equipment malfunction and others as determined from test operations.

2.2.20. MODULE COST PARAMETERS

The Stack and Balance Of Plant (BOP) are integral in the ERC cost target of $ 1,000 per kW. The stack cost are the product of the manufacturing environment at FCMC and the expected long runs of production for the electric utility sector. For the marine derivative the cost of the BOP and modular approach is key to achieving the cost target of $1,000 per kW. We are confident that as the fuel operating costs are realized the value of our approach, using a simple one-sided-fit module, will increase government and private sector-wide demand for these capital cost-competitive marine modular fuel cell power systems.

2.2.21. MODULE SERVICE LIFE

The power plants described in this Report are based on experience gained during other related studies of cost constrained systems and from the baseline of requirements determined from discussions with U.S. Coast Guard naval engineers. The list of ancillary equipments reflect those already available or necessary to provide a system integration scheme for the purposes of this engineering feasibility study. During the subsequent detailed design of a system for the repowering the VINDICATOR other equipment choices may be made based on programmatic considerations as well as the cost and availability of the required equipments. For the proposed power and services systems we have chosen a power plant of twelve (12) 215 kW stack modules or a total of 2.58 MW of power. This range of fuel cell modules corresponds roughly to the plant load of the existing diesel generator sets. The modular design can be scaled in 215 kW increments to meet higher power requirements, for example, for USCG HEC MEC cutters to 10 MW or more using existing components which will not require any more research and development. These fuel cell stacks have a MTBF of at least 40,000 hours, but expected to be about 58,000 hours and when periodically replaced over a 30 or more year ship life their power output will grow at least 10 percent. The MTBF may also lengthen as refurbishment techniques are determined from any failed stacks.

The maintenance requirements are expected to be substantially reduced compared to those of conventional generator sets. First, consider the items which will remain the same. The fuel supply and handling system is essentially unchanged. As all fuels are stored in existing ship

tankage, no special monitoring test set should be needed to ensure that the sulfur levels remain extremely low. The electrical distribution and control will remain the same. Inverter maintenance will be low because of the temperatures and air cooling, only requiring yearly cleaning and adjustment. This is similar to the normal maintenance for the diesel electric generators, which require yearly cleaning. The DFC modules will require yearly inspection and cleaning. We have estimated the time to accomplish this for twelve DFC modules. The estimated time is equal to the diesel electric generator yearly inspection and cleaning. With experience this may not be required because of the configuration and construction of the modules. The air handling system is unique to the DFC modules and will require regular maintenance cleaning and periodic air blower bearing replacement.

The major maintenance is to renew the DFC stack on a nominal 40,000 hour schedule or to install newer design modules in their place. This is accomplished using a change-out method similar to the approach perfected by gas turbine manufacturers. The DFC stack is replaced with a brand new or refurbished stack from a rotatable pool maintained by the manufacturer. This reduces down time and cost by allowing factory experts to refurbish and renew the electrolyte while reusing or recycling the old hardware. Finally, it should be noted that the cost to accomplish this would be approximately $150 dollars per kW. This is similar to the cost of diesel generator set major overhaul. However, we know that the MTBF estimates for the DFC modules are conservative and in fact may be much greater than 40,000 hours. A regular maintenance comparison of the present diesel generators and the DFC modules is shown in Table 2-1 in terms of the hours of estimated maintenance time per year.

2.2.22. MODULE REPLACEMENT

The shipping pallet protects the bottom connections and doubles as a ground foundation for unimproved storage sites. Once the module reaches the ship upper deck hatch area the shipping pallet is removed and the 4 lift rod threaded bottom-end protective "Castlenuts" are removed to check the status of the threaded ends. The protective castlenuts are replaced while the module is rigged down through the hatch and to its intended site on the deck in the fuel cell room. Just before being landed on this deck the 4 castlenuts are removed so that the threaded ends of the lift rods can be positioned directly into the 4 deck internally threaded module mounting and securing holes. Once positioned the 4 lift rods are wrench-turned simultaneously to gradually tighten down the module to the deck.

Module refurbishment is by changeout and then major system parts replacement on land or after return to the manufacturer. No overhaul type servicing would be done onboard, eliminating the need for overhaul service personnel.

2.2.23. MODULE TRANSPORT

The module is designed to be transported on standard tractor trailer, air or rail transportation system with a dry weight of approximately 15,000 pounds. A standard 40 foot tractor-trailer is capable of shipping multiple modules and remain under cube and gross vehicle weight limitations.

TABLE 2-1 ANNUAL MAINTENANCE COMPARISON IN HOURS

MAINTENANCE HRS REQUIRED TYPE	NUMBER YEARLY	DIESEL GENERATOR SET	DFC MODULES
ANNUAL INSPECTION	ONE	180	112
10,000 HOUR OVERHAUL (TOP)	0.867	260	---
20,000 HOUR OVERHAUL	0.438	88	---
GENERATOR ANNUAL CLEANING	ONE	40	---
AIR SYSTEM ANNUAL CLEANING	ONE	---	28
INVERTER ANNUAL CLEANING	ONE	---	28
TOTAL HOURS		568	168

2.2.24. MODULE TRENDS AND EXPECTED CHANGES

Three expected manufacturing changes to the module configuration could have substantial positive impact to module performance. The first is a new configuration of stack manufacture that will substantially eliminate two out of four of the plates currently used in each cell thereby reducing cost and weight. ERC is in the process of securing appropriate patents. This will increase the stack power density. This will help the USCG effort and make the results of this feasibility study more conservative.

Second, an ERC advanced design improvement is expected which could change some of the cell external manifolding to internal manifolding. This should improve efficiency in stack manufacture and may reduce cost.

3. BASELINE SHIP CONFIGURATION

The baseline ship configuration has been changed to accommodate the twelve modules in the place of the four diesel generators in the main engine space, the stacks and exhaust silencers have been removed leaving a modified top side that allows 360 degree viewing from the existing pilothouse. The tankage although not changed has been reduced to hold only 55 tons to accommodate less draft and greater speed and endurance. As a method to reduce cost and risk, five 200 kW DC to AC inverter have been located in the propulsion power conditioning system. This allows slow speed operations using the existing AC to DC Thyristor drive system to function as designed for speeds up to 6 knots and for the fuel cells to be switched to direct drive connections using custom switchgear for speed above 6 knots. This will result in minor changes to the propulsion control system. At slow speeds the ship will experience approximately 20% fuel economy loss as compared to a fully integrated DC drive switchgear system for the slow speeds. This will be the subject of a preliminary design trade-off to establish the benefits of one switchgear system versus the above described hybrid chosen to demonstrate feasibility. The following subsections discuss the findings presented in this overview.

3.1. Operating Scenario

The yearly operating scenario proposed is used to evaluate propulsion systems by comparison. The operating profile is expressed in the form of percent (%) time at each speed on an annual basis from 0 to full speed of about 12 knots and time at anchor or "cold iron" for maintenance and repair. The electric loads are specified as kW and a percentage of time on an annual basis. Table 3-1 below contains the operating profile for speed and electric load expressed as the annual percent of time.

TABLE 3-1 SPEED AND LOAD VERSUS TIME

Ship Speed kn	Estimated % Annual Hours	Average kW Electric Load	Estimated % Annual Hours
0	10	000	10
1	05	050	05
2	05	100	05
3	05	150	10
4	05	200	10
5	05	250	10
6	05	300	10
7	05	350	10
8	05	400	10
9	05	450	05
10	10	500	05
11	15	550	05
12	20	600	05

The economic analyses uses a fleet of 10 vessels operating for a period of 20 years. The comparison of the baseline design and the fuel cell configuration will focus on deltas which will clearly demonstrate the approximate differences in performance as opposed to absolute performance in the real world mission environment which can be chaotic.

3.1.1. OPERATING PROFILE

The operating profile was selected after reviewing with USCG operators experience operating the USCG VINDICATOR (WMEC-3). The ship has not accumulated a regular schedule of operations or a mission profile. The operating profile focuses the majority of operations near full speed (15% and 20% of the time at 11 and 12 knots respectively) and the median electric load of 250 kW, with about 10% of the time each year at anchor and/or "cold iron" and an electric load of 0 kW. This operating profile will allow a comparison of the baseline plant and the new fuel cell plant that will give a realistic delta for the relatively undefined operating profile of the ship as used for the USCG mission.

3.1.2. TRANSIT AND CRUISING SPEED

The expected transit speed is 12 knots and the expected cruising speed is 11 knots. This is reflected in the operating profile.

3.1.3. DRYDOCK AND MAINTENANCE PROFILE

The drydock and maintenance profile for the VINDICATOR is expected to be approximately every five years. The dry docking will allow hull preservation and complex overhaul activities for the ship. The fuel cell modules are expected to be de-coupled from this schedule just as the present generators are removed for complex maintenance. This will allow extended availability for mission-essential activities. The hull preservation is the critical path. This has been the experience with gas turbine and modular diesel prime movers for both the USCG and US Navy vessels.

3.1.4. SPECIAL OPERATIONS

The VINDICATOR has been used for drug interdiction and may be used for northern fisheries patrols. Increased speed and endurance are desirable characteristics that fuel cells offer the ship as a possible repowering up to 3.2 or more megawatts using the available space in the main machinery space. The details of this option are the subject of another feasibility study. The VINDICATOR is capable of accommodating special operations with the present powering.

3.2. PROPULSION REQUIREMENTS

The current propulsion requirement is to use the balance of available power after the ship service power electric loads are satisfied. This methodology will continue to be used. The fuel cell modules and all estimated weight deletes and adds yield a feasible ship that is some

300 tons lighter with a draft of 12 feet vice 15 feet. The reduction of mission electric loads allow up to two (2) megawatts of propulsion power to be made available at full power. With the reduced draft and full load displacement the ship is capable approximately 14 knots.

3.3. Electric Load Requirements

The VINDICATOR revised electric loads are contained in Table 3-2 below:

TABLE 3-2 REVISED ELECTRICAL LOADS

SWBS LINE	LOAD DESCRIPTION	CONN. MAXIMUM	IN PORT/ ANCHOR MAXIMUM	CRUISE/ TRANSIT MAXIMUM	SPECIAL/ TOWING MAXIMUM
	TOTALS KW	3,491.04	458.35	1,490.41	807.66
	SURTASS REMOVALS				
00202	SURTASS WINCH	-61.5	0	0	0
00203	EMERG. SURTASS WINCH	-28	0	0	0
00701	POWER CONV 400 HZ	-18.65	0	0	0
00702	POWER CONV 60 HZ	-225	0	0	0
00825	SURTASS DYHR	-0.5	-0.05	-0.05	-0.05
00998	SURTASS POWER	-211.7	-21.17	-31.76	-74.56
	SUBTOTALS KW	2,945.69	437.13	1,458.6	733.05
	FUEL CELL ADDS				
00606	FUEL CELL SUPP. FAN	30	4.39	15.35	8.77
00702	PWR CONV 60 HZ 5% LOSS	74.9	21.4	74.9	42.8
	SUBTOTAL	104.9	25.79	90.25	51.57
	FUEL CELL TOTAL KW	3,050.59	462.92	1,548.85	784.62

3.3.1. IN PORT AND AT ANCHOR

The VINDICATOR is in port or at anchor approximately 10% of the time based on the assumed operating profile. The electric load requirement is at or near zero (0) 10% of the time, which follows the in-port condition.

3.3.2. TRANSIT AND CRUISING

The VINDICATOR is in transit and or cruising approximately 25% of the time based on the assumed operating profile. The electric load requirement averages near the range of 300 kW 50% of the time, which follows the electric load operating profile assumed. Other combinations are possible and may be calculated using the assumed profile.

3.3.3. ON STATION

The VINDICATOR is on station approximately 45% of the time based on the assumed operating profile. The electric load requirement averages near the range of 300 kW 50% of the time, which follows the electric load operating profile assumed. Other combinations are possible and may be calculated using the assumed profile.

3.3.4. ON STATION SPECIAL OPERATIONS

The VINDICATOR is on station special operations approximately 10% of the time based on the assumed operating profile. The electric load requirement averages 500 kW 5% of the time, which follows the electric load operating profile assumed. Other combinations are possible and may be calculated using the assumed profile.

3.4. Electric Plant Description

The electric plant has two possible configurations that allow a feasible technical solution. During the preliminary design phase a cost trade-off is necessary to determine the advantages of each approach.

The first possible configuration reduces control system risk for low power/speed start up of shaft rotation for the ship when conducting normal operations and station keeping. Six 200 kW DC to AC inverters would provide ship service and propulsion generation at three (3) phase 440 VAC and three phase 600 VAC power to feed through the existing propulsion switchgear. The balance of propulsion power would be provided via a special switch gear feeding direct current at 800 VDC in a stepped increment up to 1.8 MW. This will provide (due to the 300 ton displacement reduction) for full power speed of approximately 14 knots.

The loss in low speed energy conversion efficiency is estimated at 20% total. It is made up of approximately 10% for DC to AC conversion and 10 % for AC to DC conversion, for total of 20% for the 0 to 600 kW range of propulsion control. Limited changes to the propulsion control are necessary to achieve satisfactory ship propulsion control. Project risk could be

minimized and slow speed mission effectiveness would be impacted with a minor fuel penalty in this configuration.

The second possible configuration increases efficiency and control system performance for start up of shaft rotation for the ship when conducting normal operations and station keeping. Switchgear schedule increments of 25 kW (or about 33 BHP per step) of propulsion power would provide 960 VDC power to feed through new propulsion switchgear. The switchgear would feed conditioned direct current at 800 VDC in a stepped increment up to 1.8 MW. The development and cost of the DC switchgear is a subject of a cost analysis during preliminary design.

3.4.1. PROPULSION POWER GENERATION

The total of twelve 200 kW fuel cell modules represent the new power generation capability for the ship. Both space and weight margins remain available in order to increase powering and thus ship capability without suffering fuel cost penalties until powering reaches about 6 MW or the limitations of the propulsion motors are exceeded.

The main machinery space has been configured to allow over-the-top replacement of the fuel cell modules in 48 hours. Gas turbine ship experience would support turn around times of less than 24 hour with quick disconnect fittings, plugs and special buss work interfaces.

3.4.2. SHIP SERVICE POWER GENERATION

Completely separate ship service power generation could be provided by three 200 kW DC to 3 phase 440 V AC air cooled inverters using intake air and 160 VDC buss voltage from two dedicated fuel cell modules, which would be in addition to the ten propulsion power generation modules discussed above. The system must be capable of operation in parallel, independent and dual mode with any combination of one (1) or two (2) fuel cell module and one (1), two (2), or three (3) inverters. Type 1 power and 400 Hz power could be provided using the present motor generator sets. Ship service power loads from 0 to 600 kW are expected from the review of the electric load analysis.

3.4.3. EMERGENCY POWER GENERATION

The 400 HP Caterpillar Model D3408TA prime mover and Kato, 250 kW, 400 VAC, three phase generator emergency power generation diesel generator could still be used and fed using sulfur free diesel fuel. The present switchgear interface is completely compatible with the new power generation scheme.

3.4.4. PROPULSION POWER CONDITIONING AND DISTRIBUTION

The Propulsion Power Conditioning and Distribution will require the partial removal and replacement of the cabling and switchgear for the most energy conversion efficient case which is the direct DC switchgear to DC motor drive configuration. The weight assumed reflects

this case with 95% removal and 115% replacement in the appropriate SWBS Group. The step increments as described above are frame sizes of G, C and D to achieve 30 BHP to 1000 BHP for each drive motor through a shunt, DC link fuse and MD contractor. Separate excitation to the motor field control is provided by battery and/or the Fuel Cell Module VDC buss circuit at 24 Amps and 72 Amps. The emergency generator loads could also be replaced by a fuel cell module once the quick start methods proposed in this feasibility study are proven.

3.4.5. SHIP SERVICE POWER DISTRIBUTION

The existing ship service power distribution system has been retained to function as designed with no changes for all 60 Hz distribution loads. All 400 Hz loads have been removed from the ship.

The 175 kW required for ships lighting could be replaced by the fuel cell module VDC buss and a DC switch board, which could reduce the lighting load of the ship by 40%. This option would be very attractive for a new construction ship that has distributed fuel cell modules with VDC buss and DC switchboards to handle the lighting load centers.

3.4.6. SHORE POWER DISTRIBUTION

The shore power distribution system has been retained to function as designed with no changes.

3.5. Propulsion Control System

The Propulsion Control System has been retained and modified to function as designed with no changes other than the scheduling of inverter and switchgear to apply appropriate voltage and power appropriate to a speed range of from 0 to 14 knots. The propulsion control weight estimate reflects modest changes to weight and kg based on the "worst case" described above as removing the SCRs and developing a special purpose switchgear to mate the fuel cell DC output voltage to the propulsion motors.

3.6. Ship Service Power Control System

The ship service power control system will require changes to accommodate the load management and the possible rotation of fuel cells modules on and off line using special DC switchgear. Otherwise the control system interface with the ship service power control system will function as designed for the diesel engine configuration.

3.7. Auxiliary Systems

The lube oil and conditioning system and jacket water system for the diesel engines has been not been retained because it is not needed to operate the new fuel cell powered ship configuration.

3.7.1. PROPULSION GENERATOR FUEL SYSTEM

The ship's propulsion generator fuel system was originally sized at 143,000 gallons to support full power operations. A day tank would be appropriate for the operation of the fuel cell modules and has been sized at approximately 3,000 gallons (about 31 hours of operation at full output). An automatic fill system will transfer fuel to the day tank when it senses that the fuel level is below the 50% mark.

3.7.2. SHIP SERVICE DISTILLERS AND POTABLE WATER SYSTEM

The ship service distillers and potable water system has been retained to function as designed with no changes. The approximately 5,100 gallon storage tank is not appropriate and should be increased to about 12,000 gallons storage using 40 gallons per man aboard. The distilled water production from the fuel cell varies as a direct function of load. It is significant at about one gallon per kWh produced. The combined output of the present distiller units is about 3,000 GPD.

3.7.3. HEATING, VENTILATION AND AIR CONDITIONING (HVAC) FOR ENGINE ROOM

Heating, ventilation and air conditioning (HVAC) for the engine room has been retained to function as designed with no changes. The aspirated fuel cell module intake and exhaust will reduce the interplay of heat transfer to the engine room. Air to air heat exchangers could be used to supplement the heating as a function of fuel cell module load.

3.7.4. HIGH PRESSURE START AIR SYSTEM

The high pressure start air system has been retained to function as designed with no changes to support the APU start air necessary for each fuel cell module during start up from "cold iron".

3.7.5. JACKET WATER COOLING SYSTEM

The jacket water cooling system has not been retained as it is not needed to function as designed.

3.7.6. LUBE OIL SYSTEM

The diesel engine lube oil storage and conditioning system has been 85% removed from the ship along the prime movers and generators. Other supporting auxiliary systems were not removed because weight and cost effectiveness would not be substantially or positively effected.

3.8. Machinery Box Layout

The "machinery box" layout has been substantially changed to reflect reduced air flow and service interface arrangement implied by one sided fit fuel cell modules as shown in the "main machinery" space arrangement drawings. The various arrangement drawings are now explained. Figure 3-1 shows the plan view of the 15 ft 8 inches long by 34 ft wide "machinery space" formerly occupied by the four diesel electric generators. Diesel generator auxiliaries have not been removed in this drawing. The first possible fuel cell module layouts is shown, with the base of each module used as the "template". 12 modules are shown in three rows. Frame numbers are seen on the ship's centerline. In this layout only one narrow centerline aisle is provided.

Figure 3-2 shows the second possible layout, based on increasing the fore-aft space by 7 inches to fit 2 modules end-to-end longitudinally. Again, the diesel electric auxiliaries have not been removed from this drawing. 12 modules are shown in this layout with 7 fore-aft aisles for access. However, the "services" ducting and piping to and from each module below the "floor" interfere with each other. Therefore, the arrangement was again reconsidered to improve this key design aspect.

The third arrangement for fuel cell modules is shown in Figure 3-3. Four longitudinal rows of three modules each are shown. The diesel generator auxiliaries were removed from the drawing and the fore-aft module "floor"/deck area was increased from 16 ft 3 inches to 20 ft 4 inches. The individual fuel cell modules each require for "services" supplied by under-floor ducts and/or piping. They are: Inlet Air and Exhaust both supplied via rectangular cross-section ducts; as well as, Water and Fuel, provided by piping from appropriate distribution manifolds.

Figure 3-4 shows the "phantom" arrangement of the under-floor distribution ducts and manifolds, as well as piping distribution and piping manifolds. The inlet air is provided from a common blower shown on the port side aft, identified as "AIR INTAKE BLOWER". The athwartships air duct manifolding is aft of the modular fuel cell floor area.

The exhaust ducts and manifolding is forward of the modular fuel cell area and is shown feeding the "EXHAUST HEAT EXCHANGERS 1 (and 2)". The product water condensed by the second heat exchanger flows to the "WATER TANK" from which the supply of water for each of the 12 modules is then drawn. The water manifold is forward of the modular fuel cell area with appropriate water piping to each module.

The fuel supply enters from the after end of the space and is shown by the "FUEL PUMP", which feeds the 12 modules through appropriate manifolding and piping, as shown. No electrical connections or control/monitoring connections to each module are shown on these drawings but similar distribution of these "services" connections will apply. None of the described "services" physically interfere with other ones in this layout. The exhaust connection to the ship's "exhaust stack" is shown on the starboard side, forward of the fuel cell module "floor"/deck area.

FIGURE 3-1 FIRST POSSIBLE FUEL CELL MODULAR LAYOUT (3 ROWS OF 4 MODULES)

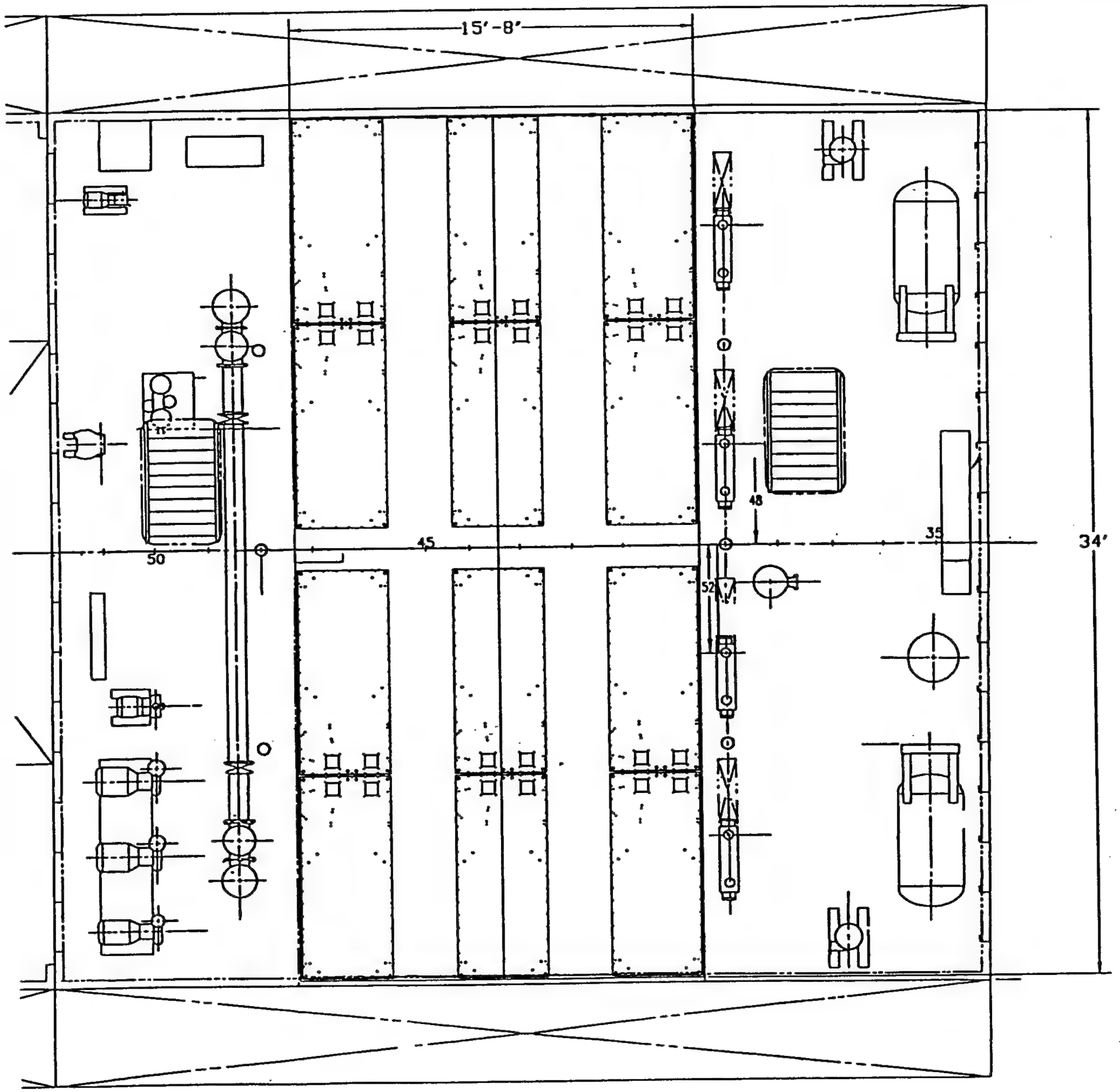


FIGURE 3-2 SECOND POSSIBLE FUEL CELL MODULAR LAYOUT, INCREASED LONGITUDINAL ACCESS

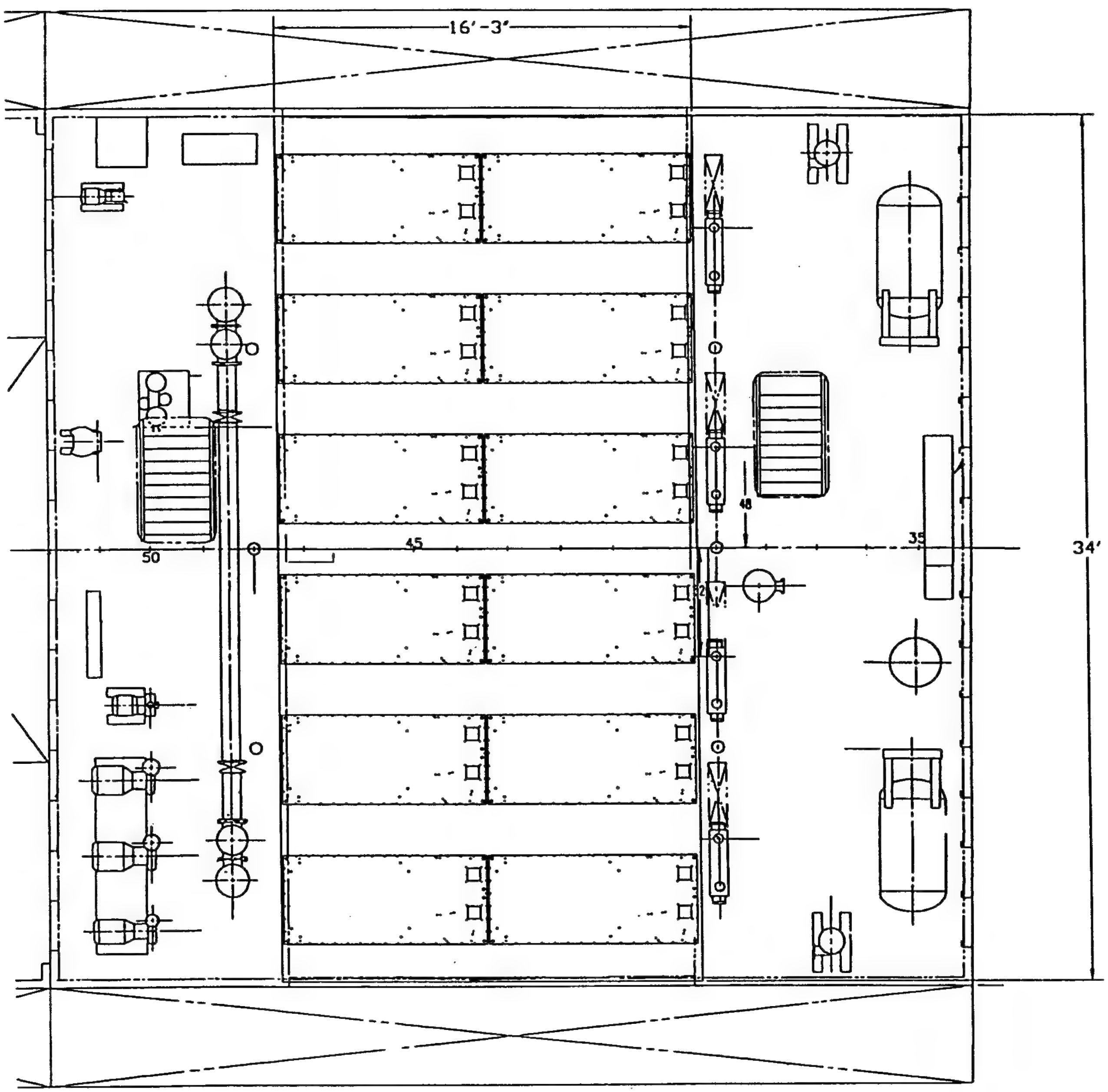


FIGURE 3-3 THIRD, CHOSEN, FUEL CELL MODULAR LAYOUT WITH FULL ACCESS

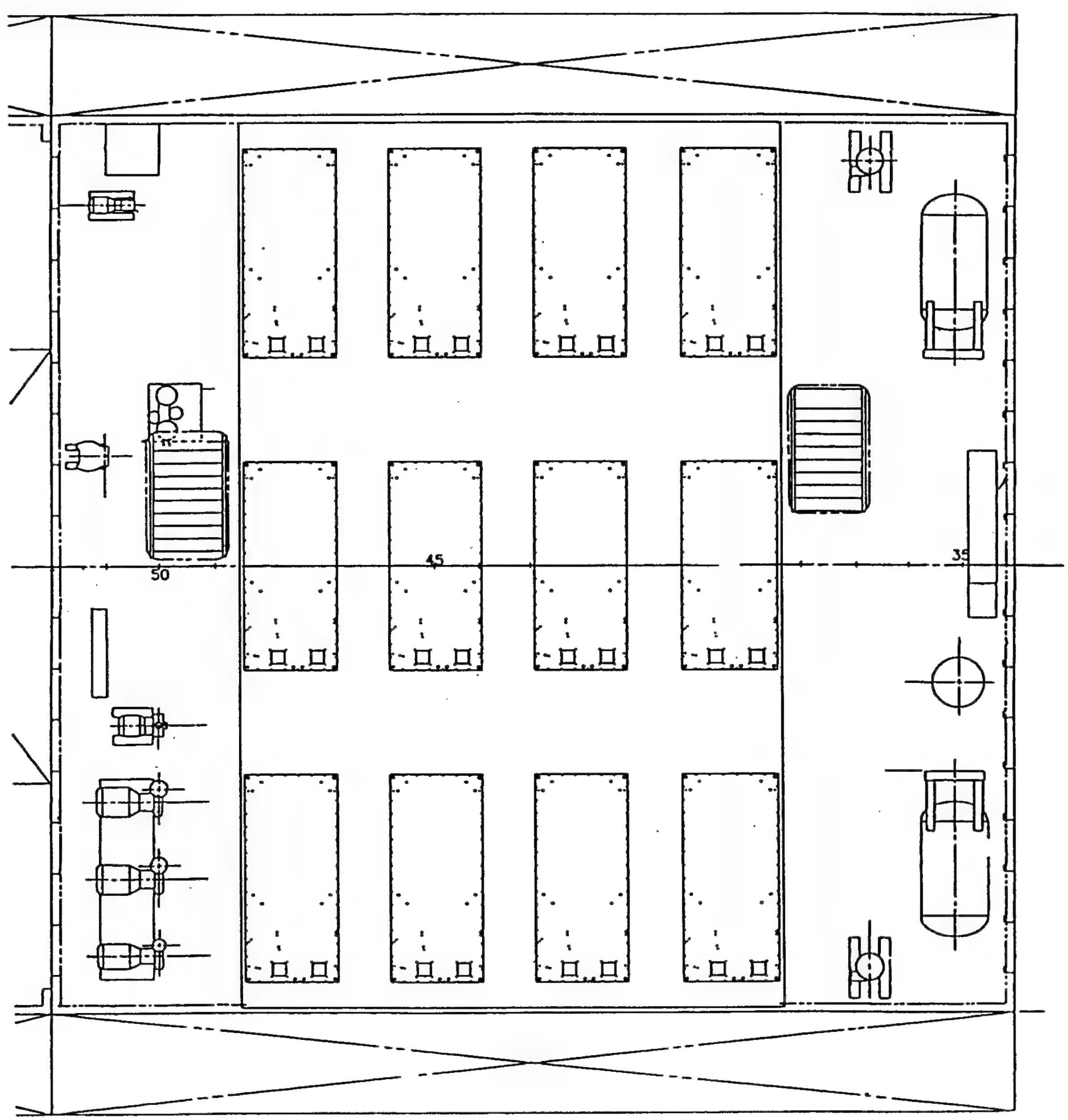


FIGURE 3-4 LOCATIONS OF FUEL CELL MODULAR "SERVICES" CONNECTIONS

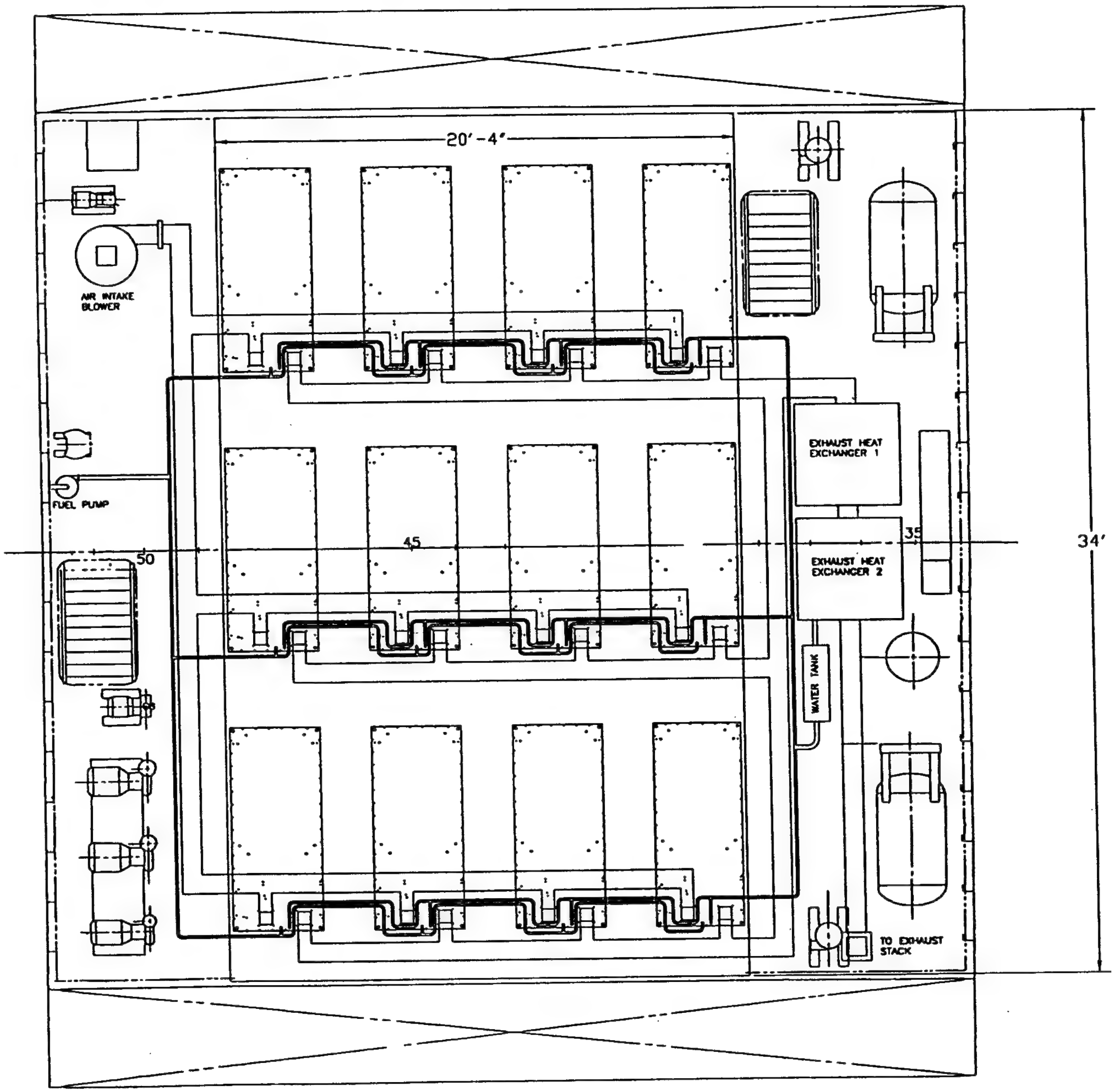


Figure 3-5 shows the "floor"/deck without modules. The module mounting holes and the "services" openings in the floor are clearly visible in this view.

Figure 3-6 shows how the 12 modules will appear in plan view with the "phantom" arrangement of the "services" connections not shown below the floor. For scaling purposes a "scale model" of a male figure is shown (in plan view) on the steps in the port forward corner of the drawing.

Figure 3-7 shows a starboard side inboard profile elevation view of the reconfigured fuel cell power plant room. The fore-aft "floor"/deck length provides 2 inches of clearance between the forward row of fuel cell modules and the grating deck and 2 inches of clearance between the aft row of fuel cell modules and the grating deck shown. The center-to-center fore-aft modular spacing is 5 ft 6 inches. An elevation view of the "scale model" (5 ft 9 inch tall) male figure is located between two modules to show the access space. The "floor"/deck below two modules and two of the "services" connections ducts under the floor are shown, above the watertight void "tank top".

3.9. Intake and Exhaust Uptake Layout Changes

In order to show the air intake and the exhaust uptake aspects of the fuel cell power system and the changes made to the baseline ship configuration, a number of drawings are now described.

Figure 3-8 shows the baseline diesel generator exhaust uptakes, both port and starboard in an elevation inboard Section A-A drawing at Frame 51 looking forward. This elevation drawing was taken from the USCG T-AGOS ship drawing 2592234E titled "Diesel Exhaust Diagrammatic Arrangement". Note that two "silencers" are located in each exhaust uptake for a total of four. Fuel cells are silent and therefore require no "silencers". Further, the reduction of 50% of the fuel cell power plant's fuel rate, compared to diesel engines, means a equivalent reduction in the air intake of 50% and a corresponding reduction in the exhaust of 50%. Finally, because fuel cells are not air polluting systems there are no "unburned hydrocarbons", NO_X or SO_X emanations from the fuel cell powered ship. This baseline elevation section drawing does not accurately show the true ship outline, only the internal uptakes from the engine room and the exhaust stacks protruding from the bridge deck above.

The greatly simplified fuel cell power system elevation drawing is shown in Figure 3-9. Both of the bridge deck stacks have been completely removed. Therefore, the pilot house will now have 360^{o} unobstructed visibility. Below the bridge deck are placed 6 shrouded vent openings facing aft on both port and starboard sides on the respective "uptakes". The port side "uptakes" now becomes the engine room air intake. The fuel cells' exhaust is vented from the 6 aft-facing starboard side shrouded vent openings shown.

Figure 3-10 provides details on the location of the 6 aft-facing shrouded vent openings, as seen in this starboard side elevation view. No stack(s) are now visible above the bridge deck

FIGURE 3-5 CLEAR "FLOOR"/DECK SPACE FOR FUEL CELL MODULES

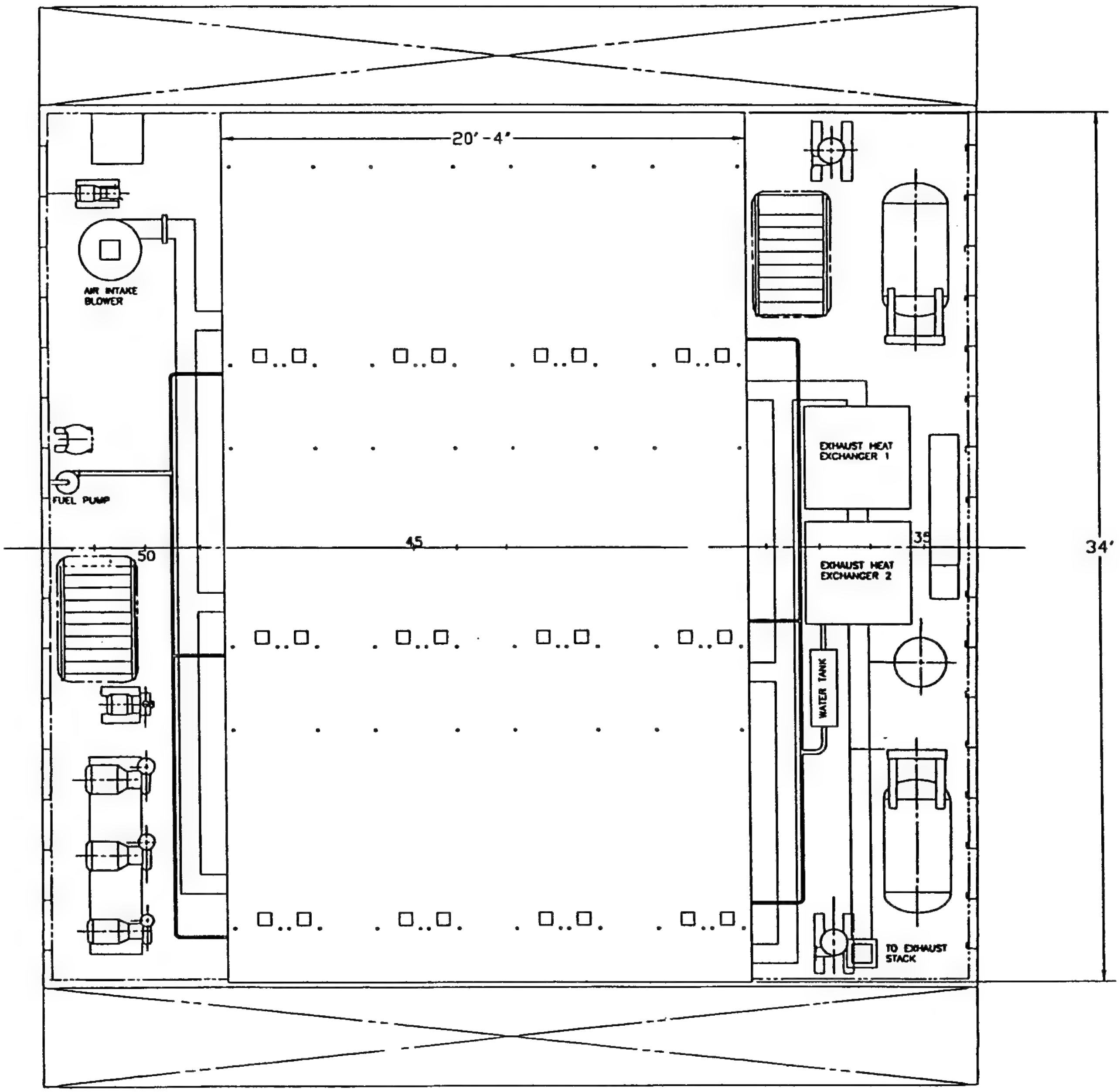


FIGURE 3-6 12 FUEL CELL MODULES IN PLAN VIEW ON "FLOOR"/DECK

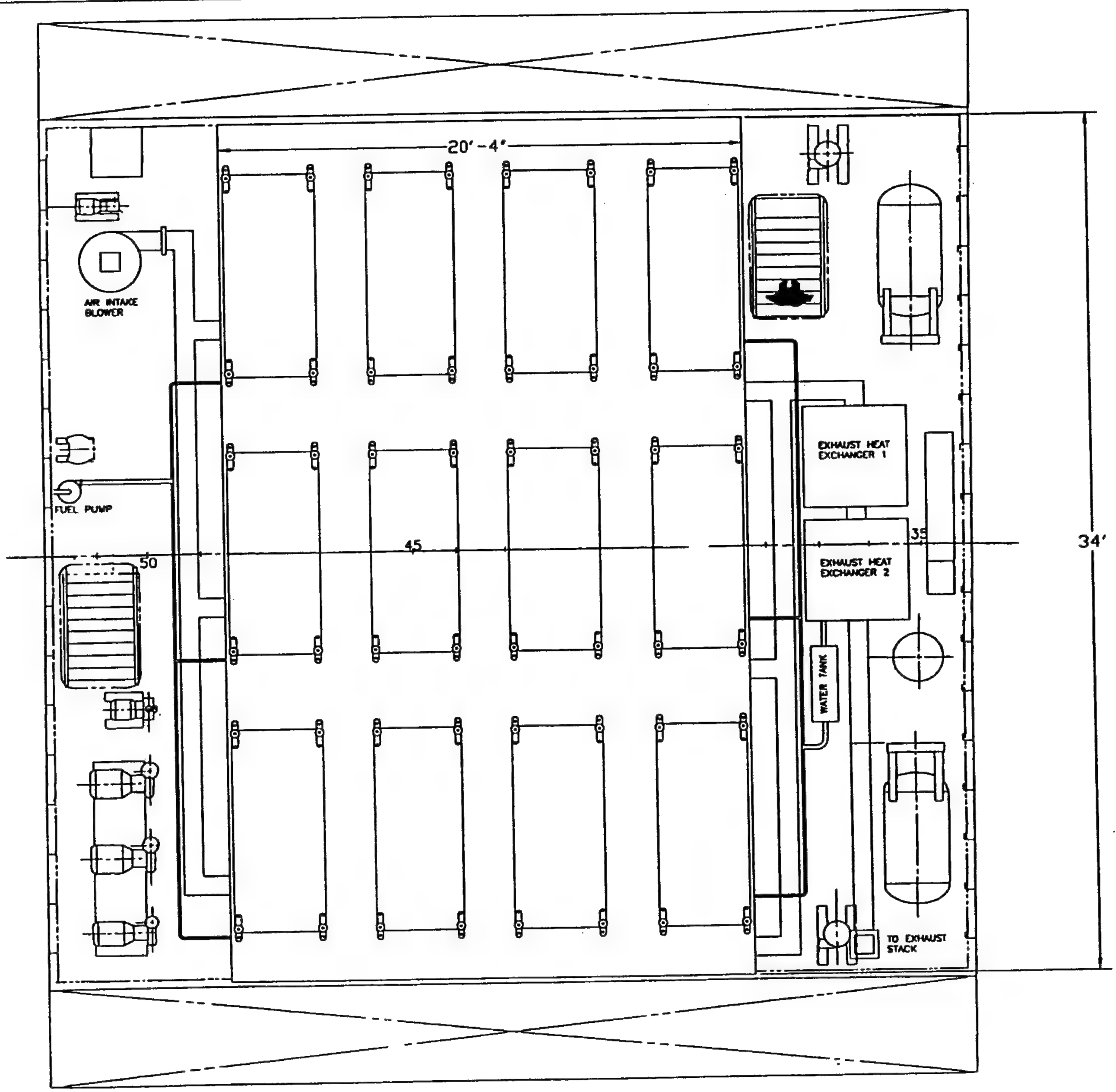


FIGURE 3-7 INBOARD PROFILE OF FUEL CELL ROOM

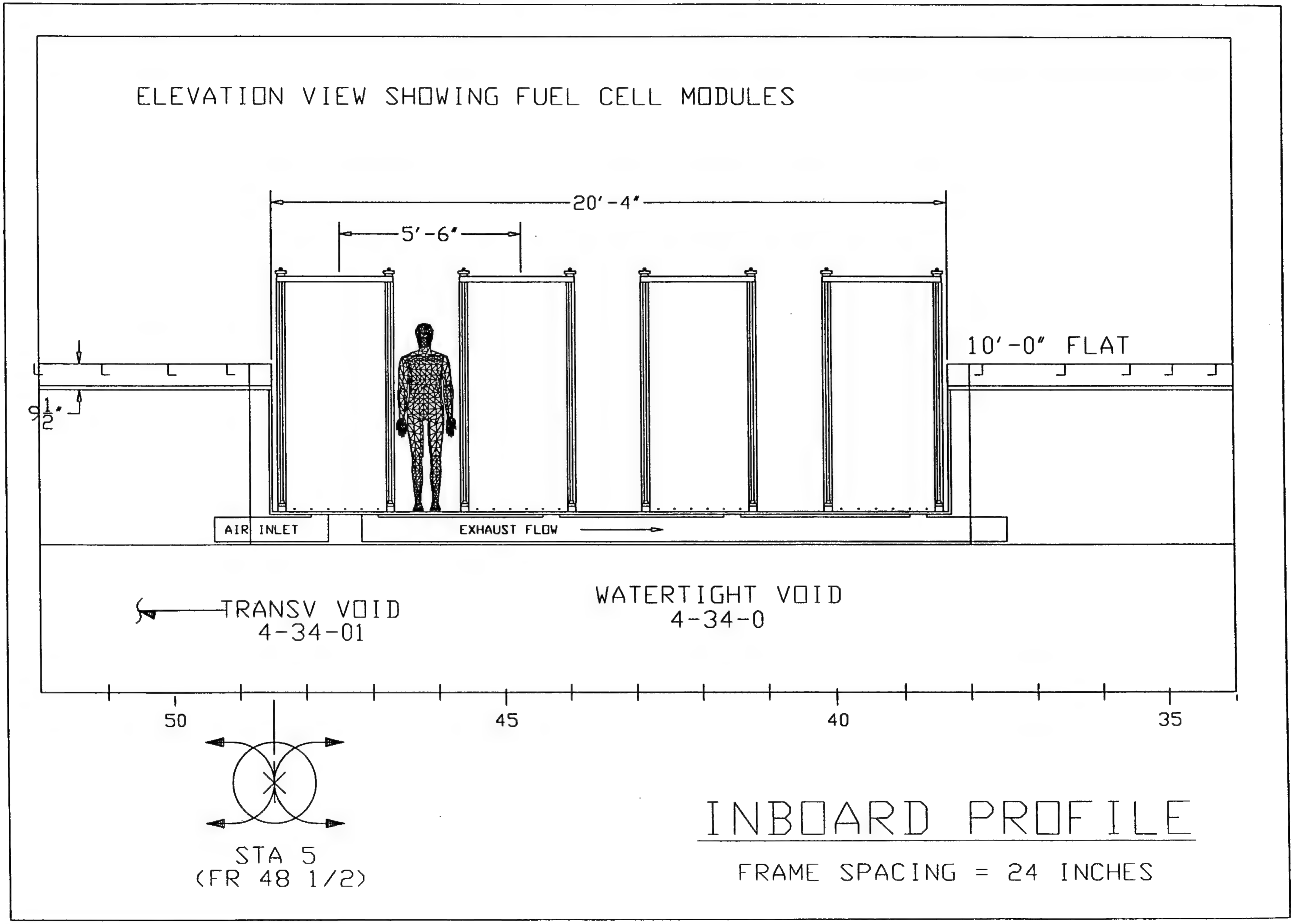
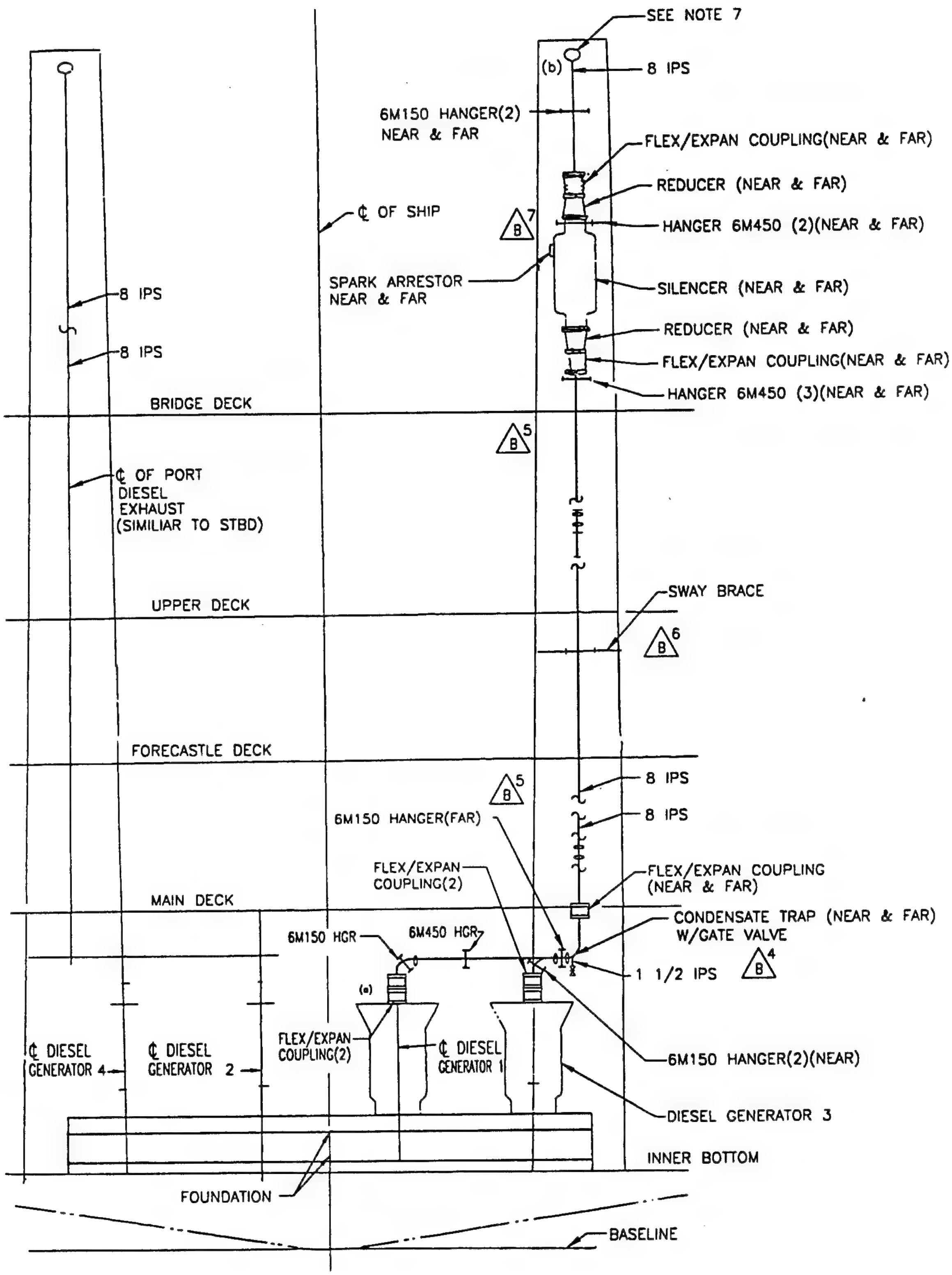


FIGURE 3-8 DIESEL ENGINE EXHAUST UPTAKES



SECTION A–A

FIGURE 3-9 FUEL CELL POWERED SHIP INTAKE AND UPTAKE

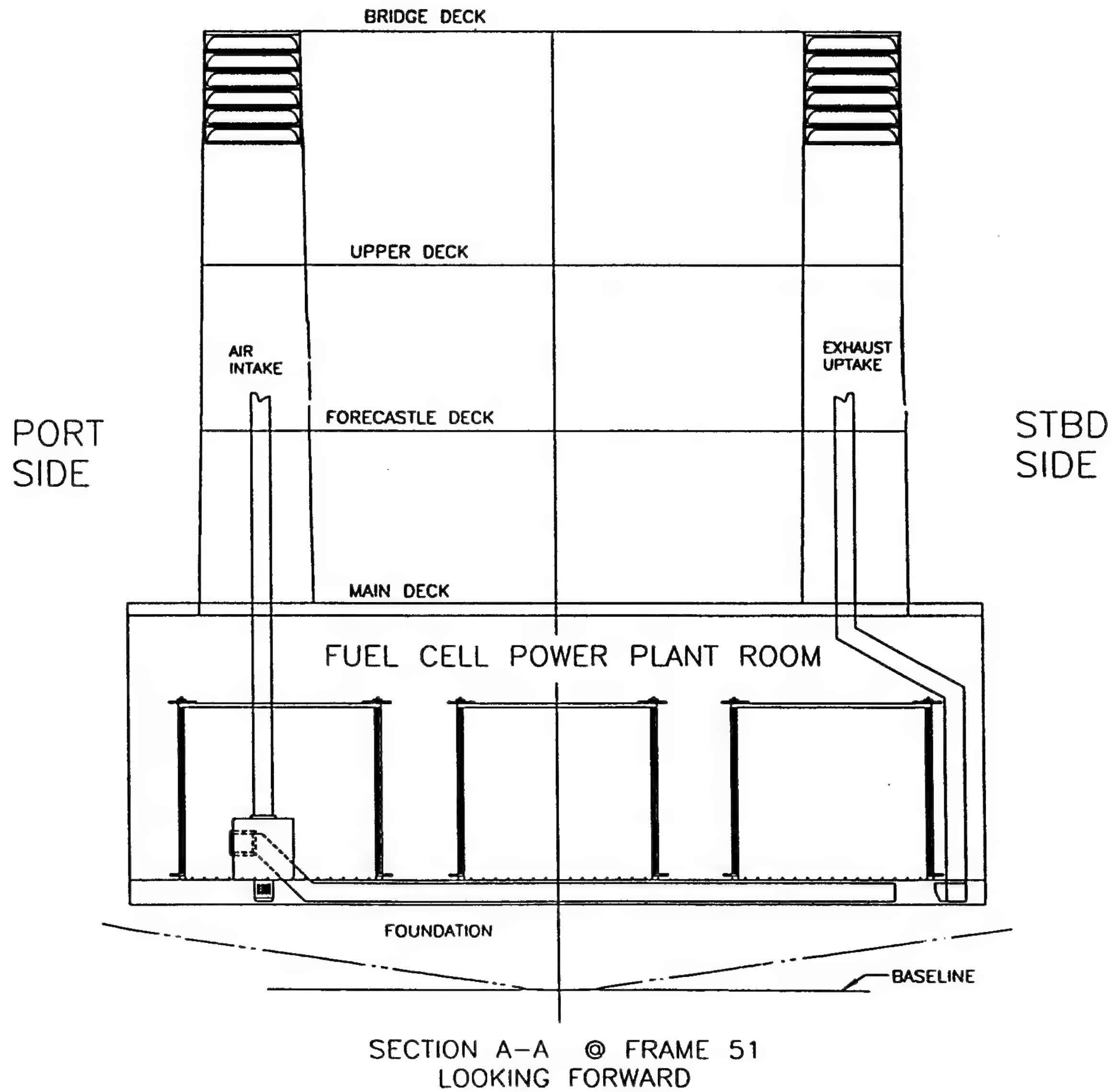
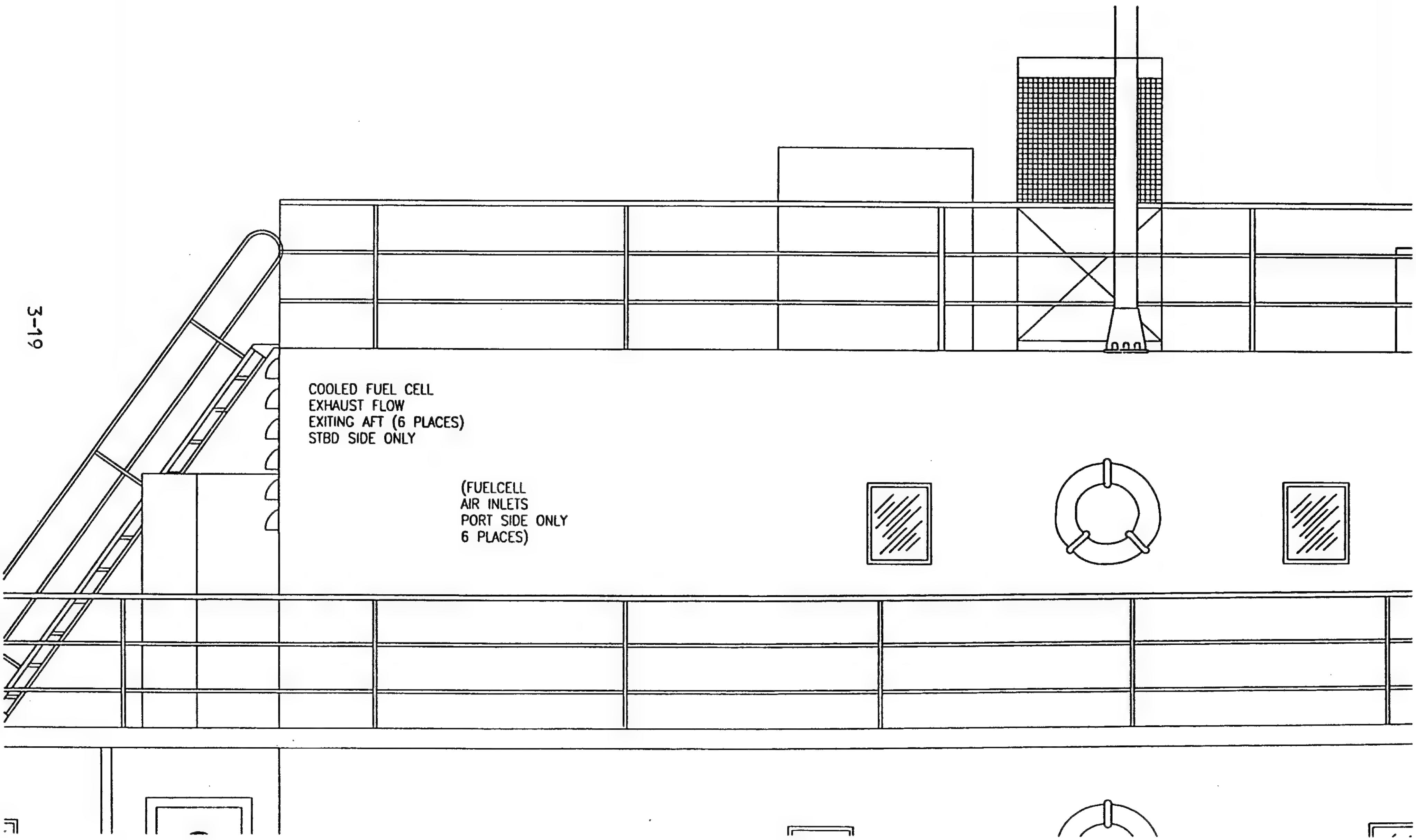


FIGURE 3-10 STARBOARD SIDE DETAIL OF EXHAUST FLOW VENTS



because they have been removed.

Figure 3-11 shows the outboard profile of the "Stack-Free" fuel cell powered WMEC-3 VINDICATOR. The truncation of the two exhaust stacks and the removal of the four diesel engine silencers therein deletes considerable superstructure weight from the ship which improves the stability.

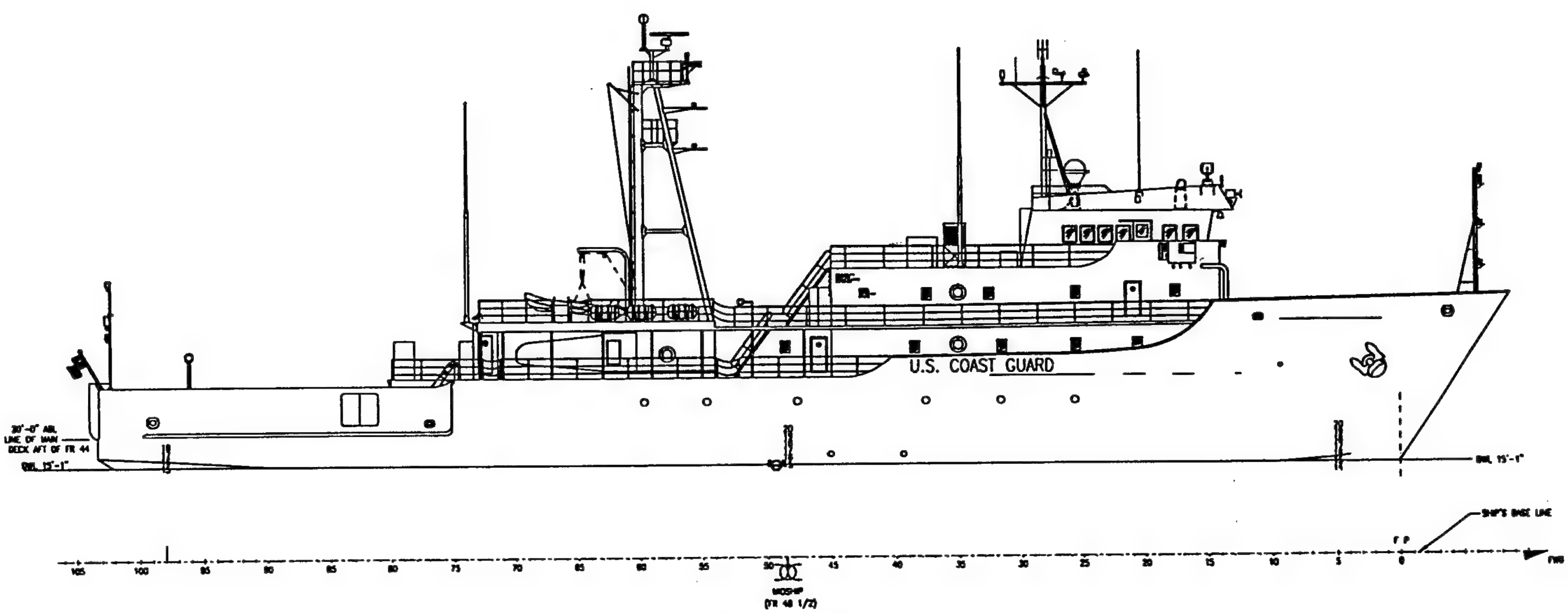
3.10. Regulatory Body Requirements

The ship before and after repowering meets US Navy, MSC and ABS (Maltese Cross) A1 E Ice Strengthened Class "C" requirement per the US Navy Ship Specification. The change in draft and displacement would not affect the Class "C" ABS rating as ballasting with seawater is an option when operations are expected in free ocean ice conditions.

The after mast could have been removed and an alternative mast head and range light design would allow greater free deck area aft of the pilot house so that helicopter operations could be design into the ship. This design feasibility task is outside the scope of the present repowering study. This is a regulatory body impact that may need to be addressed in the preliminary design to better accommodate the real world mission profile of a 14 knot VINDICATOR class with much greater helicopter capabilities.

FIGURE 3-11 THE FUEL CELL REPOWERED SHIP PROFILE

"STACK-FREE" FUEL CELL POWERED WMEC-3 VINDICATOR



OUTBOARD PROFILE

4. SHIP REPOWERING TECHNICAL DESIGN CONSIDERATIONS

The following sections give an overview of the Ship Repowering Technical Design Considerations.

4.1. Fuel Cell Modular Arrangement

The recommended system arrangement is based on four longitudinal rows of three modules athwartship. The arrangement is formulated on the engine room width of thirty-four (34) ft and the fuel cell module dimensions. The 2.4 MW system arrangement will allow rapid module installation, operation and replacement. The seven foot module height allows rigging from above, roller or skid installation. The fuel cell interface floor would be pre-installed with services, ducts and electrical connections. Careful installation of clear space, insulation and strength members to carry the load of 2,000 pounds per square foot or 14 pounds per square inch is necessary to prevent deformation of the inset tank tops.

4.1.1. REMOVAL OF SOUND ISOLATION RAFTS

The removal of the diesel engine generator sound isolation rafts is accomplished by disassemble of the bolted pieces into fixtures small enough to pass out the access hatch. This task removes all the weight associated with the sound isolation rafts which are not required by the silent fuel cell power system.

4.2. Main Machinery "Box" Studies

As explained in Section 3.8 with Figures 3-1 through 3-7, the new fuel cell "machinery box" was laid out with the eight (8) foot dimension of the fuel cell modules oriented athwartship. It is actually somewhat imprecise to refer to the new fuel cell layout as the "machinery box" because there will not be any of the traditional power generating engines and rotating machines. The efficiency of the athwartship orientation was easily determined to be superior because of the resulting increase in available space for more module per arrangement as well as superior "services" connections access to each module. It became clear during the analysis of the layout of the interfaces and service ducts/pipes that distribution was made much easier and efficient with the athwartship orientation. The one possible drawback to this orientation is the necessity to rotate each fuel cell module 90 degrees during through-the-hatch installation and removal. This is a minor concern.

4.2.1. SYSTEM SIZING AND CALCULATIONS

The following is an overview of the existing diesel generator plant:

4.2.1.1. Present System

The present system VINDICATOR engine room consists of four supercharged and after-cooled Caterpillar D398 diesel electric generators which produce AC three phase power

output at 60 (Hz). The 60 Hz power is then rectified to DC by a bank of silicon controlled rectifiers (SCR) located aft of the four diesel electric generators. The intake manifold pressure of the diesel engines is 20.6 pounds per square inch absolute (PSIA).

4.2.1.2. Efficiency

The diesel engine driven electric generators are stated to be 92% efficient and at full power the SCR control is stated to be 80% efficient. These two efficiency values then yield an electrical efficiency of 73.6% or 74%. This efficiency number can then be multiplied by the energy conversion efficiency of the diesel engine to yield the Fuel-to-DC-power electrical conversion efficiency of the power system. Alternatively, because the brake specific fuel consumption (BSFC) of the diesel engines is known and exhibits the classical curve of all heat engines, namely increased BSFC as throttle setting is reduced, the long term BSFC can be estimated. Figure 4-1 shows the diesel engine BSFC curve as a function of throttle setting.

4.2 1.3. Effective BSFC

Assume a ship long term duty cycle of:

- 50% of the time at either 80% or 100% throttle setting, with a resultant 0.251 kg/kWh.
- 50% of the time at 25% throttle setting or lower, with a resultant 0.306 kg/kWh.

$$0.5 \times 0.251 + 0.5 \times 0.306 = 0.279 \text{ kg/kWh.}$$

This figure is then divided by the electrical efficiency figure of 74%.

0.279/0.74 = 0.377 kg/kWh or Metric Tons/MWh as the long term BSFC.

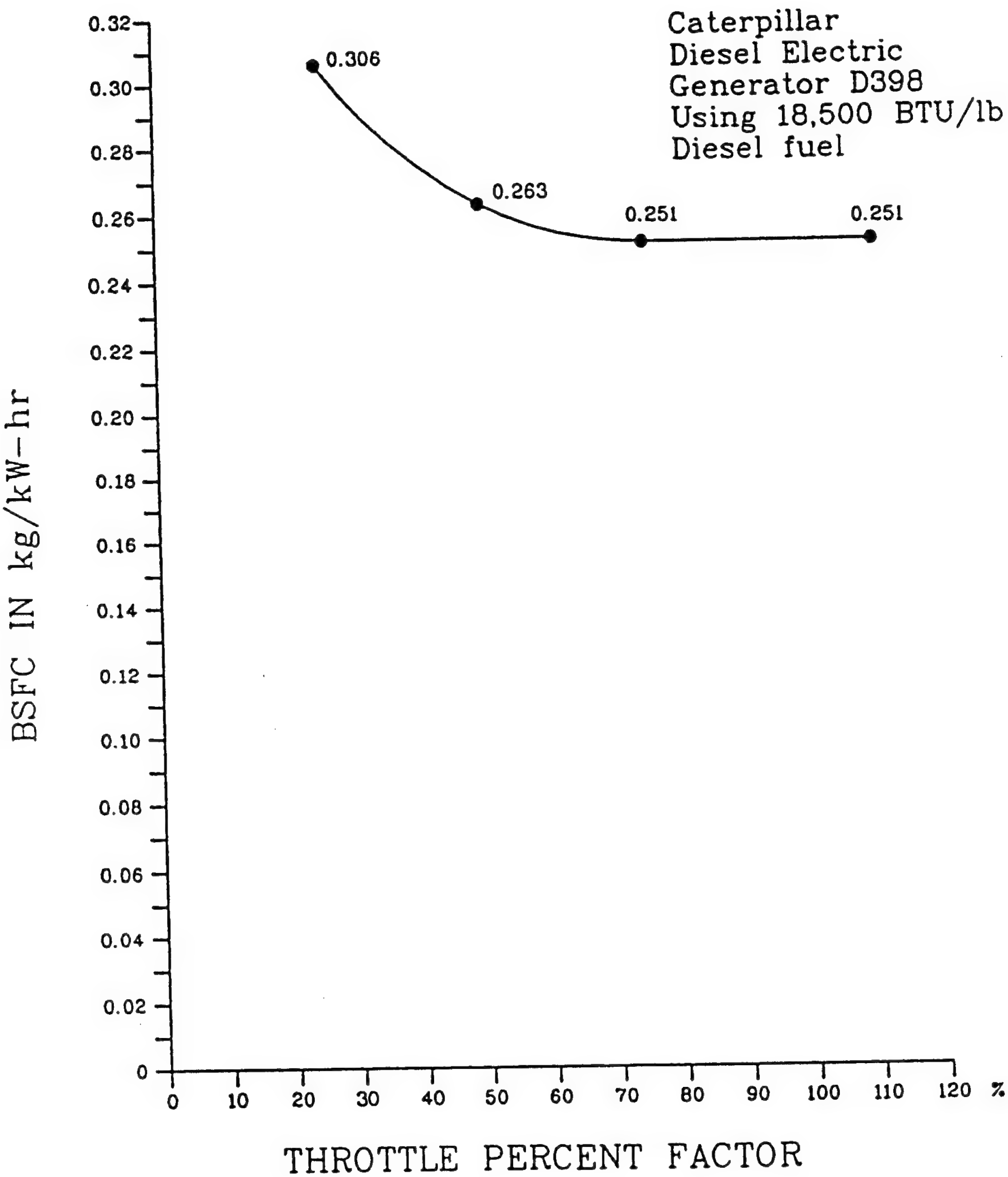
This is equivalent to 0.619 lbs/SHP hour.

4.2.1.4. Propulsion Motors and Auxiliary Power Load

Two 800 hp 750 VDC propulsion motors are fitted to the ship.
2 x 800 = 1,600 hp = 0.746 x 1,600 = 1,194 kW or 1.2 MW.
1.2 MW for propulsion + 0.400 MW for auxiliary power = 1.6 MW.

Three of the 0.6 MW diesel electric generators will produce 1.8 MW power. At least three are therefore needed to provide the nominal requirements of the ship with one rotating spare generator available for instant switch over in an emergency. This accounts for the total installed power level of 2.4 MW.

FIGURE 4-1 VINDICATOR DIESEL ENGINE BSFC AS A FUNCTION OF THROTTLE SETTING



4.2.1.5. Fuel Cell Power System

A suitable fuel cell power system at 800 VDC can be achieved through the series connection of five molten carbonate fuel cell (MCFC) 160 VDC, 0.215 MW modules. Five such 160 VDC modules could, when electrically connected in series, produce 800 VDC at 1.075 MW. Two sets of 5 modules connected in parallel produce 2.15 MW at 800 VDC.

Two electrically parallel connected modules of 0.215 MW would provide the needed 0.4 MW auxiliary power, at 160 VDC. This power output could be inverted to 60 Hz at, say, 120 VAC and used to feed the various AC power loads of the ship.

Thus, twelve modules rated at 0.215 MW each, at 160 VDC, are recommended. Ten modules are used to provide 2.15 MW at 800 VDC for the propulsion system. Two more are used in parallel at 160 VDC to provide power for the auxiliaries at 120 VAC once inverted to AC.

4.2.1.6. Fuel Cell Module Configuration

The design of the modules was determined through the following analysis:

- The individual cell produce power at a current density of 160 Amps/ft^2 (ASF). The individual cell voltage is 0.75 VDC. The stacking rate for cells is 3 cells per inch of height.
- At 72 inches in height the stack will consist of 216 cells. (72 x 3 = 216).
- The 72 inch tall stack will fit into an 7 ft high (84 inch) module with 6 inches of space above and below the fuel cell stack for mounting purposes.
- 0.75 VDC stack x 216 = 162 VDC (~160 VDC).
- The individual cells are 2.25 ft wide x 4 ft long, or of 9 ft^2 area.
- Based on an active area per cell of 0.92 (92%) and the 160 ASF figure: 9 ft^2 x 160 ASF = 1,324.8 or 1,325 Amps per cell.
- 1,325 Amps/cell x 0.75 Volts/cell = 993.75 or 994 Watts/cell.
- 0.994 kW/cell x 216 cells = 214.6 kW or 215 kW per stack.
- To allow clearance around the stack for manifolds and insulation of 6 inches per side, the width of the module is then be 3.5 ft.

- The module length is 8 ft to account for the heat exchangers (2) and the adiabatic fuel converter as shown in the dimensioned module base plan view in Figure 4-2. This is a footprint of 28 ft^2. (8 x 3.5 = 28).

4.2.1.7. FC Module Arrangement Drawings

The construction of an individual fuel cell module is illustrated in Figures 4-3 and 4-4 showing the interior plan, and side elevation views, respectively. A perspective view of the complete module is shown in Figure 4-5. Protective transport "castlenut" covers are shown on the four hold-down threaded corner rods.

4.2.1.8. Ship "Machinery Room" Layout for Fuel Cell Modules

The machinery room width is 34 ft port to starboard. The machinery space occupied by the existing diesel electric generator sound isolation rafts is 15 ft fore-aft. This provides a "tank top" nominal deck clear space of 510 ft^2 in the plan view.

Fitting 12 modules, each having a footprint of 28 ft^2, is not difficult. Only 336 ft^2 is needed out of the available of 510 ft^2 leaving space for access and maintenance. This was shown in Figures 3-1 through 3-7 in plan and elevation views.

4.2.1.9. BSFC for the Fuel Cell Power Plant

Because fuel cell BSFC is essentially constant regardless of throttle setting, and the fuel cell power plant (with no supercharging and assuming no waste heat recovery or potable water energy credit), can reasonably be expected to have an energy conversion efficiency of at least 55%.

The following calculations apply on diesel fuel of 18,500 BTU/lb.

$$\text{Fuel rate in lbs/kWh} = \frac{3{,}413 \text{ BTU/lb}}{55\% \times 18{,}500 \text{ BTU/lb}} = 0.33 \text{ lbs/kWh.}$$

0.33 lbs/kWh/2.2 lbs/kg = 0.15 kg/kWh.

This figure is less than half of the diesel electric power system's long term BSFC of 0.377 kg/kWh, as was calculated above. (0.377/0.15 = 2.5). Therefore, the direct fuel cell module powered ship will be able to travel as much as two and a half times as far on the available fuel.

FIGURE 4-2 DIMENSIONED FUEL CELL MODULE BASE PLAN VIEW

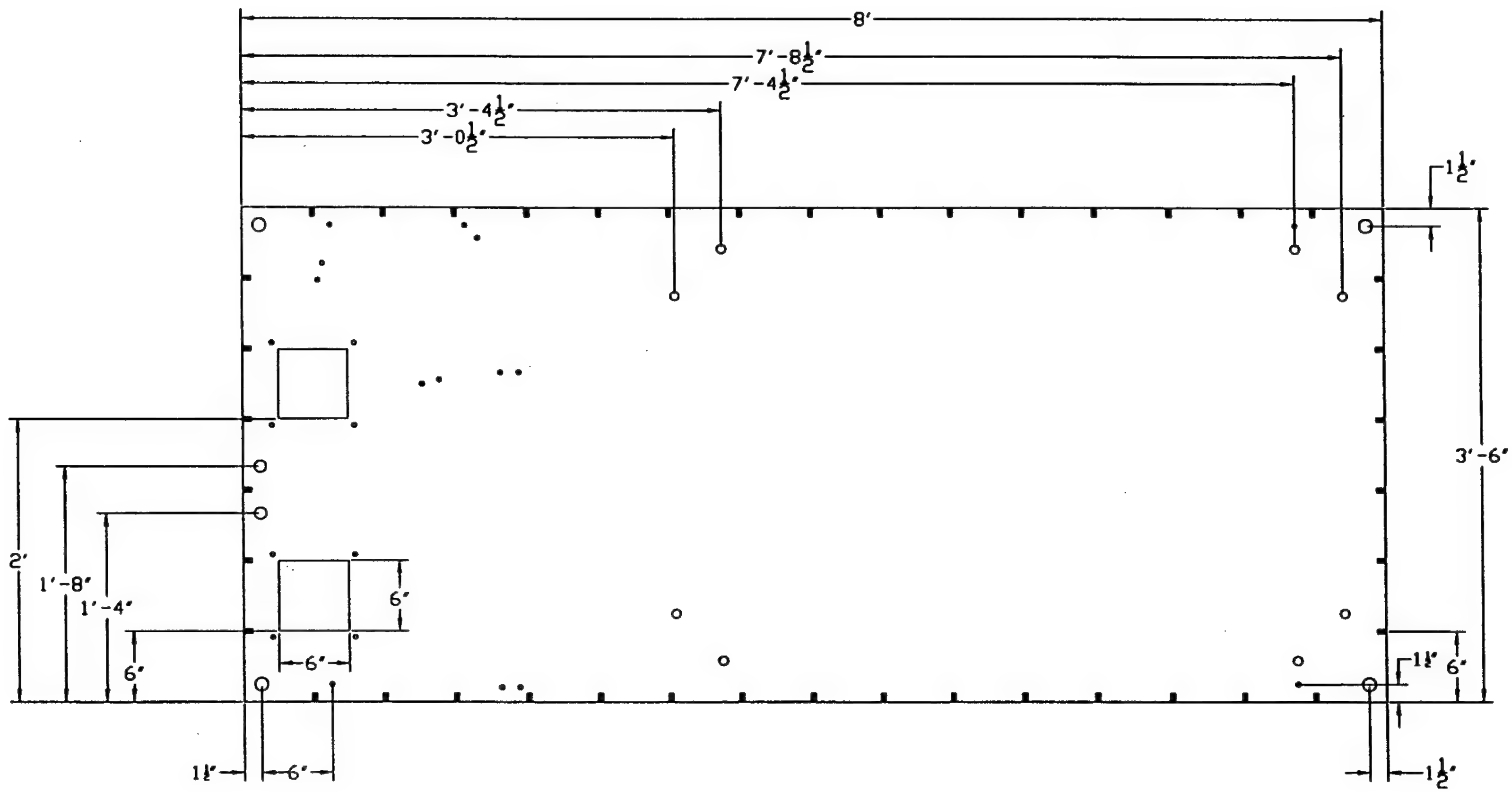


FIGURE 4-3 MODULE INTERIOR PLAN VIEW

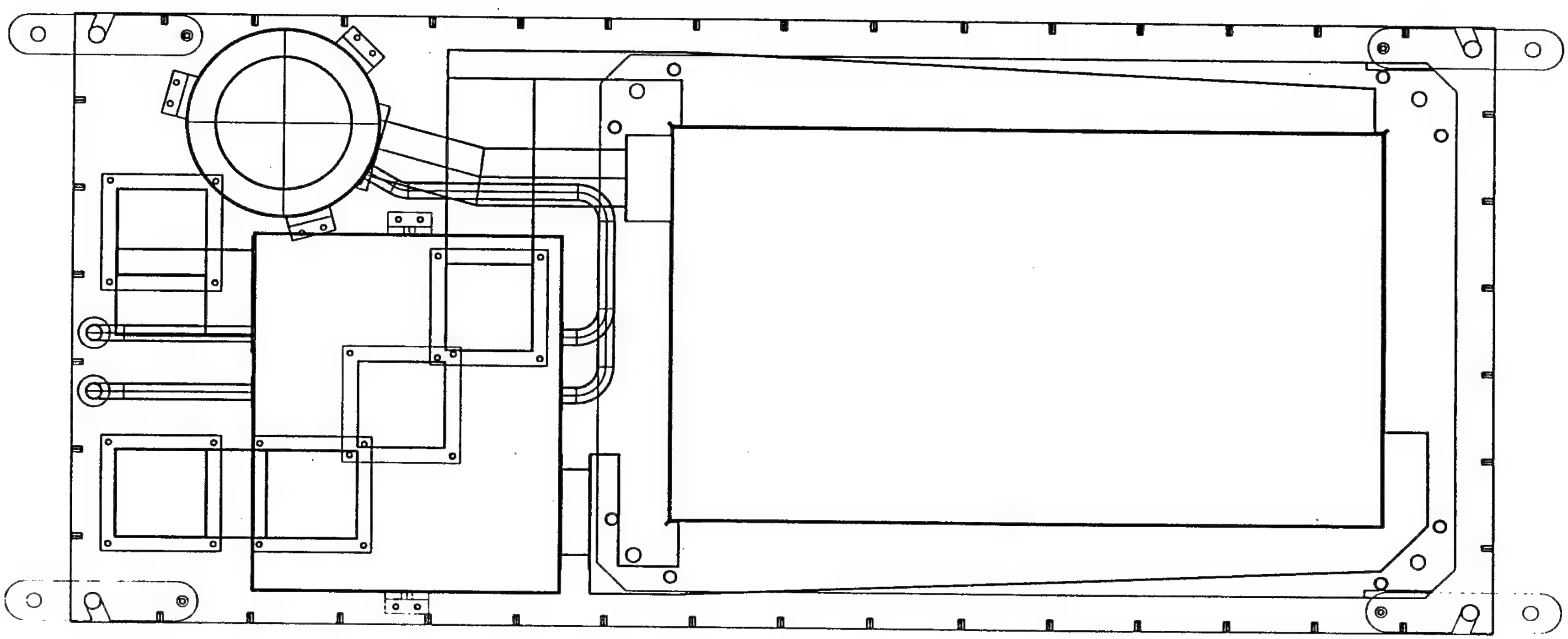


FIGURE 4-4 MODULE INTERIOR ELEVATION VIEW

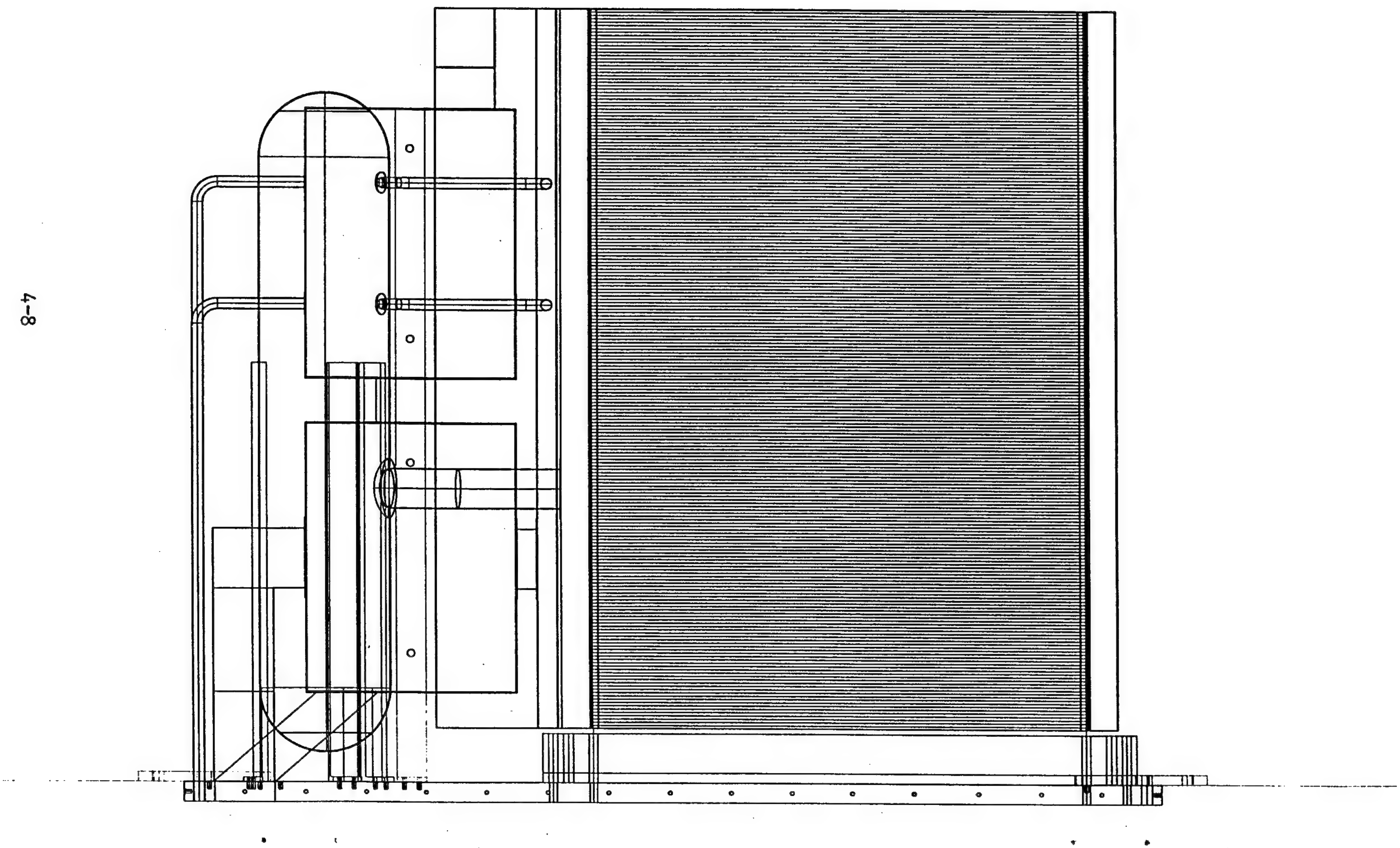
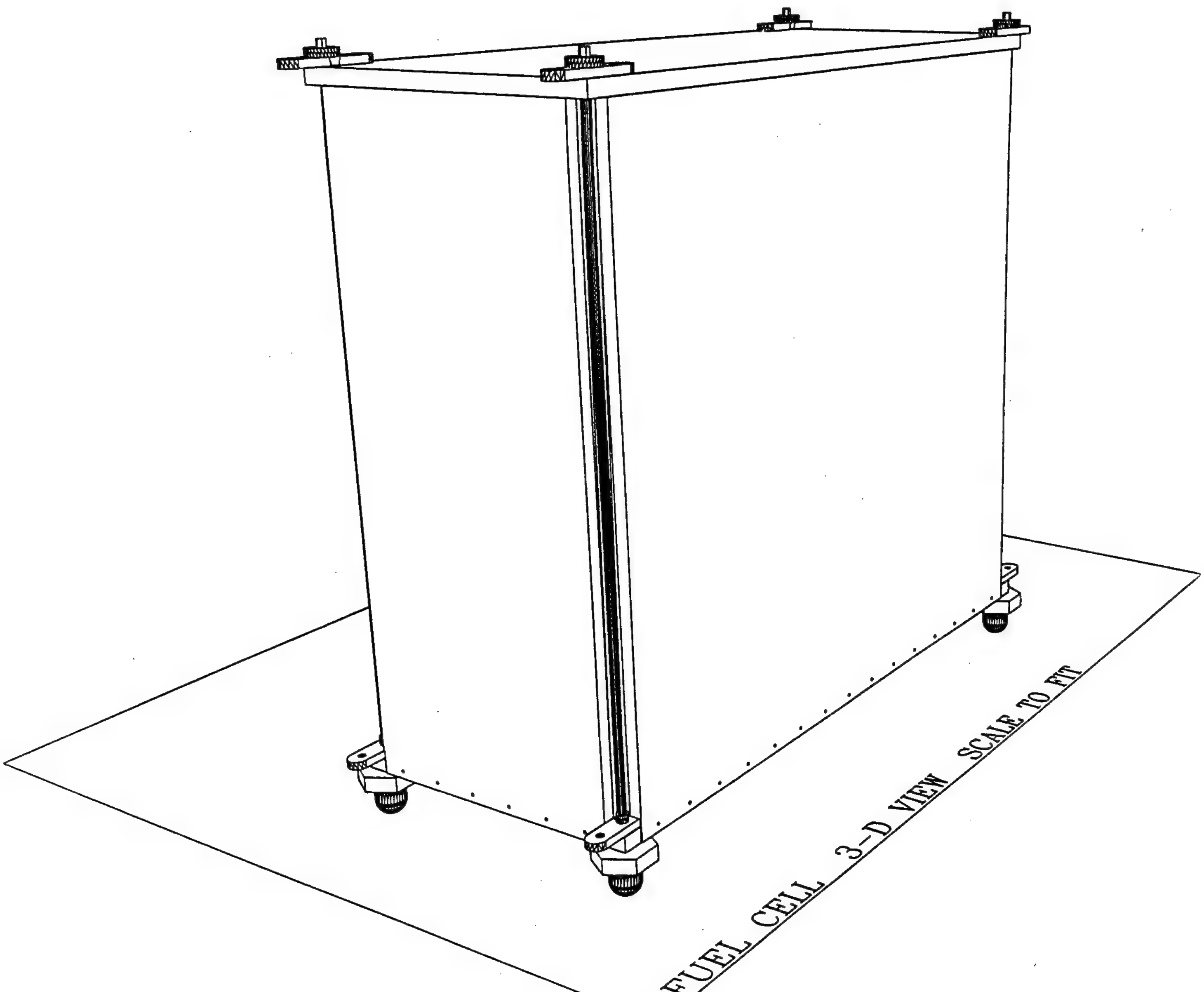


FIGURE 4-5 PERSPECTIVE VIEW OF COMPLETE 215 KW FUEL CELL POWER MODULE



4.2.2. SYSTEM PERFORMANCE CHARACTERISTICS

The DC production is a function of cell voltage and stack amperage with a response that is "stiff" like a battery. The production of hydrogen and the delivery oxygen govern the response up to the practical theoretical limits of the molten carbonate technology. The AC production via static inverters is a function of input voltage and power. AC crystal controlled frequency is plus or minus 0.04 percent. Overload protection response is less than one (1) second. All other responses are expected to be similar or superior.

4.2.2.1. Operating Limits

The VINDICATOR equipped with the twelve fuel cell modules would have a power output of 2.58 MW. It appears that as many as 24 of the 215 kW module could be accommodated in the ship "machinery space" available. The need for the void below the diesel generator/sound isolated raft type power plant engine room, for purposes of reducing ship self-noise, is no longer valid. Fuel cells make no noise. The "tank top" could therefore be lowered somewhat and various ship auxiliaries such as the water distillers could be relocated from the new "machinery spaces". The possibility of repowering could be the subject of a separate study task during the preliminary design.

4.2.2.2. Exhaust Gas Flow Rates

The calculated exhaust gas flow rate is 7,000 SCFM at full power output for both ship service and propulsion loads up to 2.58 MW. The system should be aspirated. Following the exhaust manifold for the 12 modules are heat exchangers to bring the temperature of the gas stream down to the temperature at which the exhaust steam becomes liquid water. The remainder is spent air (mostly nitrogen and CO_2). The aspiration blower drives this exhaust gas stream up the starboard exhaust trunk and overboard, as was previously shown in Figures 3-9, 3-10 and 3-11.

4.2.2.3. Intake and Vent Flow Rates

The intake and exhaust vent flow rates are on the order of 7,000 SCFM.

4.2.2.4. Potable Water Flow Rates

The fuel consumption per day is approximately 3,000 gallons and the production of potable water is at the approximate rate of one gallon per gallon of fuel consumed. Both 3,000 GPH plate type distillers would be retained to allow anchored operations. The potable water tankage should probably be expanded to 12,000 gallons to accommodate 40 gallons per day per person to increase crew comfort.

4.2.2.5. Specific Fuel Consumption Analysis

The specific fuel consumption analysis is based on actual observed fuel consumption for

both diesel engines and to a lesser degree on full scale fuel cell stacks. Conservative estimates have been used which reflect results from extensive electric utility molten carbonate lab and field tests.

DFC power plants are more efficient than any heat engine driven electrical power plant. This energy conversion efficiency is true at full power and is made at idle and at part throttle conditions. In the specific case of diesel generator power plants this difference can be determined by comparing typical performance parameters such as brake specific fuel consumption (BSFC) and/or the energy conversion efficiency. When the additional information is available as to the long term the percent of the time at various throttle settings can be factored into the calculation of the long term BSFC. When heavily loaded the BSFC for the DFC is 0.33 lbs/kWh and is 0.55 lbs/kWh for a Caterpillar diesel generator system. These BSFC values correspond respectively to full power systems efficiencies of 55 and 33 percent respectively.

4.2.3. FUEL ENDURANCE CALCULATIONS AND ANALYSIS

The amount of fuel consumed to transit a given distance is time related to the speed made good. Speed can be increased with less draft i.e. less wetted hull surface. Fuel cell propulsion will provide such a benefit as compared to diesel electric drive. Significantly reduced fuel consumption means less weight of fuel required which reduces the ship draft.

Figure 4-6 shows the horsepower/MW versus ship speed relationship for the VINDICATOR. Configuration "D" is the diesel engine generator version and configuration "F" shows the fuel cell power plant version. Due to the lesser draft (12.9 ft versus 14.9 ft) the fuel cell version "F" will permit higher speed operation at 1.8 MW of propulsion power i.e. 14 knots versus 12 knots for the "D" version.

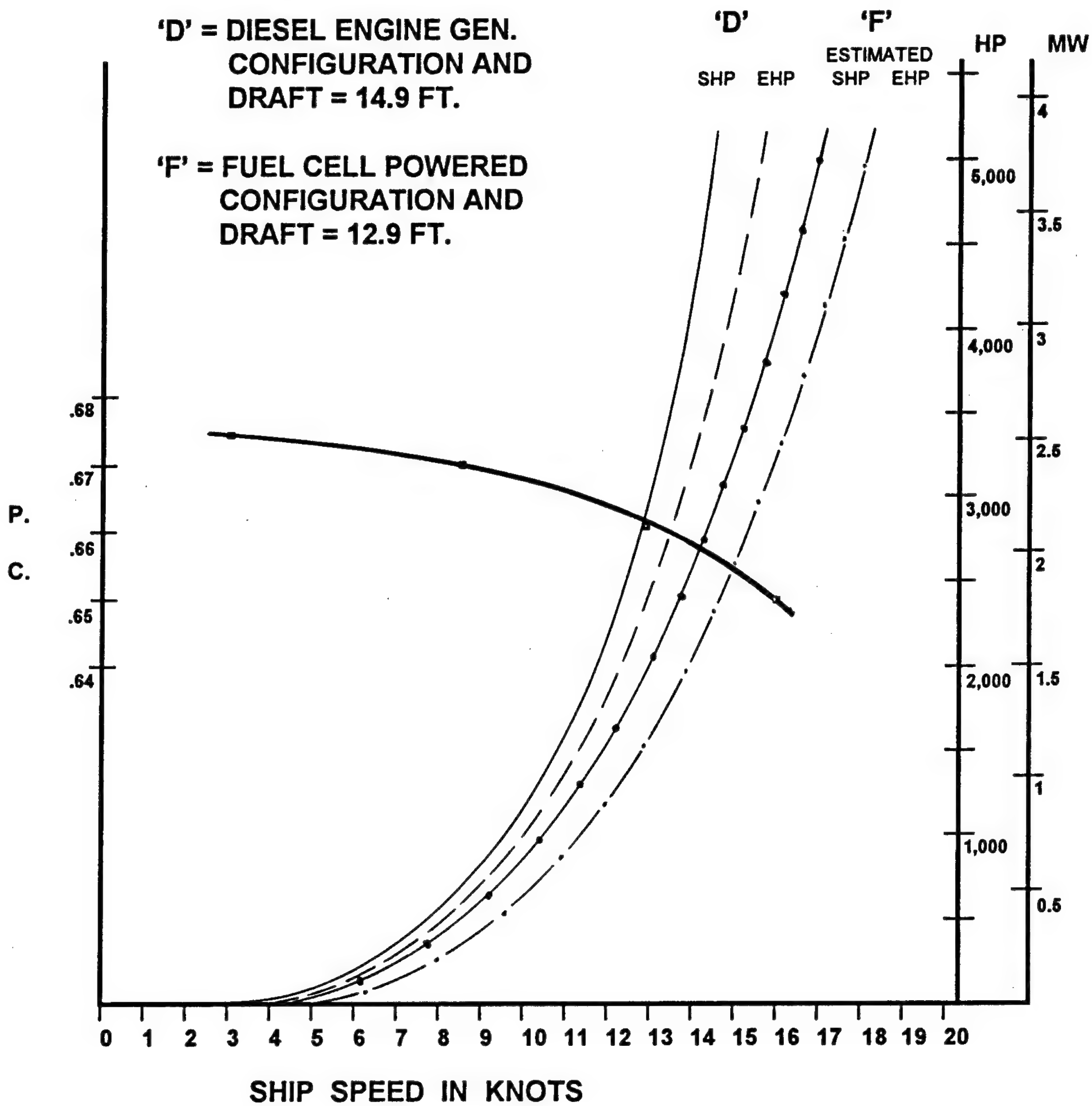
4.2.3.1. Baseline Fuel Endurance Calculations and Analysis

The VINDICATOR ship design permits a much as a 100% fuel load of 233,281 gallons of fuel for a resulting ship draft of 15.1 ft. A 25% fuel reserve would thus be 58,320 gallons. A 75% fuel load of 174,961 gallons [equivalent to 538.92 Long Tons (LT) of fuel] is calculated to provide a diesel engined configuration with a draft of 14.9 ft, as shown in Figure 4-6. The fuel consumed between the 75% condition and the 25% reserve condition is therefore 116,640 gallons, or @ 6.9 lbs/gal = 804,819 lbs, or 359.294 LT. Based on a 1,800 kW propulsion power level and 12 knots speed the diesel engined ship will consume fuel at the rate of 0.55 lbs/kWh. 804,819 lbs/0.55 lbs/kWh x 1,800 kW = 812.95 h or 813 hours. At 12 knots for 813 hours the ship will transit 9,755 nautical miles (NM).

4.2.3.2. Fuel Cell Fuel Endurance Calculations and Analysis

With the fuel cell powered ship the following situation would apply: For a 9,755 NM transit and a 14 knot speed only 696.79 or 697 hours are required. 697 h x 1,800 kW x 0.33 lbs/kWh = 413,893 lbs of fuel consumed or 184.733 LT. This equals 59,985 gallons.

FIGURE 4-6 HORSEPOWER / MW VERSUS SHIP SPEED FOR THE WMEC-3 VINDICATOR



When this fuel consumption figure is added to the previously stated 25% fuel reserve of 58,320 gal the total fuel load would then be 59,985 gal + 58,320 gal = 118,305 gal. This fuel load would then represent the "75% fuel load condition" needed. This number is 118,305 gal x 6.9 lbs/gal/2,240 lbs/LT = 364.42 LT.

The fuel cell powered ship loaded with "75% of its needed fuel" will be 538.92 LT - 364.42 LT = 174.5 LT lighter than the equivalently fueled diesel engined ship, a saving of essentially 175 LT in the variable fuel load for the identical performance at sea for a typical 9,755 NM transit at "full speed" in each case. The ship weight estimation aspect treated in Section 4.3 will draw on these findings.

Based on the fuel cell power system's excellent fuel consumption rate, or BSFC, of 0.33 lbs/kWh the full fuel tankage load of 233,281 gallons x 6.9 lbs/gal = 1,609,638 lbs. This permits the powering of the fully loaded ship, transiting at, say 12 knots, with 1,500 kW of propulsion power as follows: 1,609,638 lbs/0.33lbs/kWh/1,500 kW = 3,251 h. 3,251 h x 12 kn = 39,012 NM. This is more than one and a half times around the world at the equator before running out of fuel.

4.2.4. SHIP SYSTEMS CONFIGURATION IMPACTS

The ship systems configuration impacts were minor as compared to the improvement in ship performance and fuel rate. The following sections cover more details of the various impacts.

4.2.4.1. Main Machinery Box Arrangements

Three different arrangements were developed and the foundations weights assessed. Impacts were minor with the foundation weights approximately 34,000 pounds or about 15 long tons.

4.2.4.2. Other Ship Space Arrangements Impacts

The other impact to ship arrangements is the modification of the switchgear and six air cooled inverters.

4.2.4.3. Exhaust Uptake Arrangement Impacts

The two tall diesel exhaust stacks were removed. Aft facing intake and exhaust vent ports were added as explained and shown in Section 3. The resulting impact on the ship operation is major. With the new configuration all around visibility is available for the safe navigation of the ship. Reduced high weight also improves the vessel's overall stability, increases maximum speed a small amount as well as reducing the fuel consumption.

4.2.5. PROPULSION SYSTEM CONFIGURATION

The most substantial change to the ship is the ability to reduce by half the fuel loads, which in

turn reduce the displacement while allowing an increase to the ship maximum speed. Other changes are discussed in the following sections.

4.2.5.1. Power Conditioning System Impacts

The two DFC modules feeding the ship service power loads will feed fifty kilowatts (kW) of inverter conversion capacity to three phase, 60 Hertz 440 Volt AC power in fifty (50) kW increments. The system could be a General Electric model built up of standard components and air cooled. Two twenty five (25) kW units can be operated in parallel and coordinated to ensure performance at the rated load. This provides redundancy. In the case of inverter failure, the system could remain on the line at half rated output. The two DFC modules are configured to supply DC power to auxiliaries and the control system. DC service is available for lighting and other loads such as electrical space heating. Coordination with load centers or switch boards are possible including conventional circuit protection methods. These methods include buss tie breakers and motor operated buss ties, circuit breakers and current limiting devices.

4.2.5.2. Propulsion Control System Impacts

The propulsion control system will require substantial redesign that includes monitoring of new fuel cell module parameters including the scheduling of air and of fuel via a fuel control valve that is coordinated with the electric load. An expert in the detailed evaluation of the specific requirements will be used during the preliminary design. This effort will be substantial because it has not been completed for this type of technology in a shipboard control system environment. This control system environment has evolved into a unattended fully automatic process to reduce manning and respond to conditions that humans are not capable of controlling reliably on a continuous basis.

4.2.5.3. Air Handling System Impacts

The air handling system aboard ship is simple requiring approximately twenty fan motors that are coordinated by the control system and are design to aid in reducing engine room noise to a low level. The engine room is expected to be at a 50-60 dB level based on the experience with standard US Navy HVAC equipment. The weight impacts are modest especially due to the removal of the diesel engine silencers and the tall stacks aft of the pilot house, as was previously shown in Figures 3-9, 3-10 and 3-11.

4.2.5.4. Lube Oil and Cooling System Impacts

The lube oil and cooling system impacts are substantial in that almost all the capability will be removed along with diesel prime movers.

4.2.5.5. Auxiliary System Impacts

The impacts to the auxiliary systems are minor in that the fuel cell modules are air cooled

and require no new interfaces with the auxiliary systems.

4.2.5.6. Fuel Tankage System Impacts

The fuel tonnage has not been reduced. However, the fuel loads could have been reduced saving some 175 LT in the example discussed in Section 4.2.3.2. above. No special treatment of the tankage is needed other than cleaning prior to filling with sulfur-free diesel fuel.

4.2.5.7. Potable Water Tankage System Impacts

It is recommended that the potable water tankage for the crew be expanded to 12,000 gallons using existing void space. This will allow stockpiling the extra water needed for start up and produced during full power operations as product water by the 12 fuel cell modules. The fuel cell modules exhaust manifold heat exchangers remove the product water by condensation to a water tank. Some of this water is then be re-vaporized to be used by the 12 fuel cell modules. The water tank and the water lines to the 12 modules were previously shown in the plan view in Figure 3-4.

4.2.5.8. Support System Impacts

The lube oil and conditioning system and jacket water system has been not been retained because it is not needed to operate the new ship configuration.

4.2.6. MAINTENANCE ACCESS AND REMOVAL ROUTES

The Maintenance Access and Removal Routes have been retained and are more than adequate for the fuel cell modules. Space exist to allow rigging the cold fuel cell modules into and out of the ship in less than 24 hours using existing pad eyes and the fixtures that are part of the fuel cell module design.

4.2.6.1. Maintenance Concept

Just as gas turbines have successfully used rotable pools and aircraft support to forward reworked ready-for-issue prime movers, fuel cells can readily be this method of "maintenance". The fuel cell modules will require a minimum of routine shipboard maintenance as documented below.

4.2.6.2. Minimization of Underway Maintenance and Servicing

Selection of high MTBF components to match the high 40,000 MTBF for the fuel cell stack will minimize the number and frequency of underway maintenance and servicing. Other components need no servicing as they have no moving parts.

4.2.6.3. Stack Isolation

With twelve fuel cell modules the need to isolate a single module or stack will have a smaller incremental effect than the diesel engine generators. The special VDC switchgear will isolate each module as a normal method. In the case of a buss tie breaker failure, a manual knife switch will back up the automatic buss tie breaker.

4.2.6.4. Stack Redundancy

In general the ship in the repowered configuration can operate approximately the same as with the diesel generators with as many as three 215 kW fuel cell modules off line. The fuel cell system's smaller modular increment of load allows better matching of modules to actual load profiles.

4.2.6.5. Individual Stack Shutdown

Two methods are available to allow individual module shutdown. The first is auto stop sequencing of the fuel stop motor operated valve found in the main space. This valve would have a manual operation valve wheel that can be activated in the main space or by reach rods outside the main space. This is an important fire stop safety feature for the ship.

4.2.6.6. Exceptional Module Maintenance

The ship repowering industry team will have to make a case by case determination as to the amount of maintenance which is appropriate outside the normal factory rework facility. Minor repair of insulation and stack interconnect are possible candidates for exceptional module maintenance.

4.2.6.7. Removal Concept for Modules

The present fuel cell modular arrangement allows the changeout or pulling/removal/replacement of individual modules without removing other modules. The basic rig-out will require a skilled team of riggers to lift and rotate each cold module from transverse to a longitudinal orientation for egress out the hatch.

4.2.7. SAFETY CONSIDERATIONS FOR MODULES

The DFC stack in the fuel cell module is very safe solid state device. The manufacturer, Energy Research Corporation, has had no safety problems with the hundreds of DFC stacks built and operated to date. The device operates at high internal temperatures just as the present diesel generator sets do. The fuel subsystem is essentially the same to the point where it enters the module. This means, as with the diesel generator systems, the most significant hazard is from the fuel subsystem. Once inside the module the DFC stack processes the fuel using internal steam reformation. This reformation produces a hydrogen rich gas buffered

with carbon dioxide, nitrogen, steam and trace gases. Concentration of the hydrogen only occurs at the individual electrochemical cell reaction sites and is immediately reduced to water in each cell, which pulls more hydrogen from the reforming process. The hydrogen at the anodes form a thin layer migrating through the cell matrix, mating with the first oxygen molecule encountered and releases free electrons while becoming a water molecule. Therefore only small amounts of hydrogen are in contact with oxygen at one time. The process is stable in that it must follow the production of hydrogen plus carbon dioxide from the adjacent steam reforming step.

4.2.7.1. High Fuel Cell Stack Temperatures

The stack high temperature are confined to the insulated stack. The low pressure exhaust gases from the fuel cell module base at full power will be on the order of 500 degrees F or less.

4.2.7.2. Confined Space Safety for Modules

The aspirated system assures that the main machinery space and other spaces involved will remain clear of the exhaust as the system will leak "in" before leaking "out".

4.2.7.3. Explosive Safety

As explained above the concentrations of hydrogen rich gases only occur within a module and do not occur outside the module in the presence of ambient air. This means that fuel cells are safe compared to other heat engine power systems. All the diesel fuel lines are kept well below the flash point temperature of diesel until it is delivered into a module at which point it is then vaporized using cathode exhaust heat from within the stack.

4.3. Space and Weight Analysis

The 18 Navy Ocean Surveillance Ships of the Stalwart Class (T-AGOS-1) were built by two different shipyards. The Tacoma Boatbuilding Company (TBC) built ships 1 through 12 and ships 13 through 18 were built by Halter Marine Inc. The T-AGOS-3 VINDICATOR was built in the early 1980s. A "3 digit" Weight Estimate, dated 5/01/83, was provided to AEL in mid 1996 by the Coast Guard for the "as built" or Baseline configuration of the VINDICATOR.

4.3.1. BASELINE NAVY CONFIGURATION-AS BUILT

This Baseline TBC builder's Weight Estimate data, in 15 sheets, was not an original copy. Accordingly, it was hard to read with some calculated moment numbers being ambiguous due to their illegibility.

Accordingly, the TBC builder's 3 digit Weight Estimate sheets of data were re-calculated and put into a Windows EXCEL spreadsheet format by Weight Groups as follows:

Weight Group		Sheet No.
100	General Hull Structure	1
200	Propulsion Plant	2
300	Electric Plant	3
400	Command and Surveillance	4
500	Auxiliary Systems	5
600	Outfit and Furnishing	6
700	Armament	6
800	Margins and Variable Loads	7

The seven corrected TBC Weight Estimate EXCEL spread sheets are shown in Table 4-1 for the "as built" Navy configuration of the VINDICATOR. The reader will find the "3DIGWTRE.XLS" sheets clear and easy to read. At the bottom of each of the seven Table 1 sheets the calculated Weight Group Totals are given as well as the *"Builder's Estimates"* total numbers [shown by an asterisk (*) and italicized typeface] from the corresponding 1983 TBC Weight Estimate sheet. In some instances the column totals are exactly equal or very close while in other cases (particularly MOMENTS in FT-TONS) the numbers are different. However, the "CURRENT TONS" column totals are very close on each page.

According to the TBC Weight Estimates the Totals of Group 1-7 or the "Light Ship" is 1436.78 LT. This is the balance after the subtraction of the Group 800 "MARGINS" of 74.648 LT from the "RUN TOTAL" of 1511.425 LT.

The sheet 7 GROUP TOTALS for the CURRENT TONS is 600 LT less than the italicized "Builder's Estimates" Total. This is the variability of the fuel load primarily. The Group 822 FUEL OIL could be as much as 233,281 gallons or 718.588 LT, as opposed to the 108.329 LT shown for Group 822 on sheet 7.

4.3.2. WEIGHT IMPACTS

4.3.2.1. Navy to USCG Configuration Changes

When the T-AGOS-3 VINDICATOR was turned over to the USCG by the Navy in 1993

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1						VERTICAL	LONGITUDINAL REF TO MIDSHIP				TRANSVERSE REF TO CENTERLINE				
2					ABOVE DES BL			FORWARD	AFT		PORT			STARBOARD	
3			PERCENT	CURRENT		MOMENT		MOMENT		MOMENT		MOMENT		MOMENT	
4	GROUP	DESCRIPTION	C & A	TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	
5	100	GEN HULL STRUCT													
6	110	SHELL & SUPP STRUC													
7	111	HULL SHELL PLATING	100.000	131.734	13.760	1015.769			2.150	243.632	0.000	0.101			
8	113	INNER BOTTOM	100.000	24.472	2.730	66.926			8.260	202.094	0.000	0.036			
9	114	SHELL APPENDAGES	100.000	9.269	5.200	48.226			80.570	746.735	0.000	0.000			
10	115	STANCHIONS	100.000	2.694	22.500	60.036	16.200	43.654			2.380	6.411			
11	116	HULL LONG FRAMING	100.000	33.291	7.400	246.236	2.460	81.850			0.190	6.344			
12	117	HULL TRANSV FRAM	100.000	75.550	11.410	861.786	4.280	323.053			0.020	1.819			
13	120	HULL STRUCT BHDS													
14	121	LONG STRUCT BHDS	100.000	64.313	13.910	894.355			3.610	232.374			0.420	27.134	
15	122	TRANSVERS STR BHDS	100.000	68.728	15.810	1086.347	6.510	447.081					0.840	50.066	
16	123	TRUNKS & ENCLOS	100.000	16.885	11.860	200.309			18.560	313.445			0.010	0.205	
17	130	HULL DECKS													
18	131	MAIN HULL	100.000	59.872	19.970	1195.763			19.360	1159.361	0.070	4.456			
19	134	4TH DK HOLD-HOLD DK	100.000	18.674	4.500	84.034			10.290	192.234	0.000	0.000			
20	136	01 LEVEL-FOC'SLE DK	100.000	45.218	28.930	1308.296	13.470	609.066			0.140	6.169			
21	137	02 LEVEL-UPPER DK	100.000	40.059	37.810	1514.543	24.270	972.090			0.090	3.567			
22	138	03 LEVEL-BRIDGE DECK	100.000	13.373	46.950	627.820	39.720	531.180			0.030	0.386			
23	140	HULL PLAT & FLATS													
24	141	1ST PLATFORM	100.000	21.369	10.700	228.728			1.850	39.511			0.120	2.524	
25	150	DK HOUS STRUCTURES	100.000	3.835	24.420	93.656			56.980	218.503	2.250	4.638			
26	151	01 LEV DKHS STRUCT	100.000	29.010	33.370	968.120	5.110	148.223					0.020	0.698	
27	152	02 LEV DKHS STRUCT	100.000	17.173	42.410	728.375	22.260	382.308					1.360	23.352	
28	153	03 LEV DKHS STRUCT	100.000	7.072	52.110	368.570	57.020	403.237					0.060	0.404	
29	154	04 LEV DKHS STRUCT	100.000	7.551	57.040	430.711	55.190	416.705			0.000	0.000			
30	160	SPECIAL STRUCTURES	100.000	5.252	30.790	161.694			76.150	399.967	1.510	7.938			
31	161	STRL CAST, FORG, WLD	100.000	5.066	34.420	174.361	88.050	446.028			0.000	0.000			
32	162	STACKS & MACKS	100.000	6.559	55.900	366.631	13.430	88.110			0.000	0.000			
33	163	SEA CHESTS	100.000	0.166	2.410	0.400			0.000	0.000			2.070	0.343	
34	167	HULL STRUCT CLOSURS	98.377	9.902	21.760	215.456			19.000	188.135	0.130	1.323			
35	168	DECKHS STRUCT CLOS	100.000	3.320	40.060	132.976			6.980	23.174	0.080	0.258			
36	170	MASTS													
37	171	MASTS, TWRS, TETRAP	92.194	5.672	60.570	343.552			1.030	5.833	0.050	0.296			
38	180	FOUNDATIONS													
39	182	PROP PLANT FOUNDAT	100.000	14.904	8.240	122.838			35.650	534.367	0.030	0.388			
40	183	ELECTRIC FOUNDATNS	100.000	32.917	7.250	238.545	9.610	316.393					0.630	20.649	
41	184	COMMND & SURV FDNS	97.300	4.459	32.760	146.095			18.030	80.419			0.250	1.129	
42	185	AUX SYSTEM FDNS	100.000	10.607	14.020	148.673	6.850	72.687			0.970	10.292			
43	186	OUTFIT & FURNISH FDNS	77.431	0.940	23.700	22.271	2.830	2.659					1.290	1.210	
44	190	SPECIAL PURPOSE SYST													
45	197	WELDMENT	0.000	16.112	18.770	302.370	0.740	11.938					0.090	1.444	
46	198	FREE FLOODING LIQUIDS	100.000	0.876	2.960	2.593			0.000	0.000			1.010	0.885	
47	199	HULL REP PRTS & SP TLS	0.000	0.536	37.000	17.143	95.000	50.893					0.340	0.182	
48															
49	Calculat	GROUP TOTALS		807.430	17.864	14424.204	6.622	5347.155	5.672	4579.784	0.067	54.422	0.161	130.225	
50	*	*Builder's Estimates*	*97.824*	*807.429*	*18.860*	*15225.001*	*0.900*	*727.376*					*0.100*	*80.007*	

TABLE 4-1 NAVY VINDICATOR WEIGHT REPORT 3DIGWTRE.XLS Sheet 1 **AS BUILT BY TACOMA BOAT SHIPYARD**

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
51						VERTICAL	LONGITUDINAL REF TO MIDSHIP				TRANSVERSE REF TO CENTERLINE				
52					ABOVE DES BL			FORWARD	AFT		PORT			STARBOARD	
53			PERCENT	CURRENT		MOMENT		MOMENT		MOMENT		MOMENT		MOMENT	
54	GROUP	DESCRIPTION	C & A	TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	
55	200	PROPULSION PLANT													
56	230	PROPULSION UNITS													
57	235	ELECTRIC PROPULSION	100.000	32.321	9.670	312.548			37.000	1195.893	0.000	0.000			
58	240	TRANS & PROPULS SYST													
59	243	PROPULSION SHAFTING	91.965	12.100	6.950	84.052			68.060	823.546			0.030	0.358	
60	244	PROPUL SHAF BEARNGS	100.000	0.379	6.470	3.747			77.940	45.130	0.000	0.000			
61	245	PROPULSORS	100.000	2.236	4.500	10.061			93.000	207.921	0.000	0.000			
62	250	PROPULSION SUPP SYST													
63	252	PROPULSION CONT SYST	81.787	1.674	18.340	30.710			7.710	12.910	7.460	12.490			
64	256	CRCLT & CLNG SW SYST	100.000	2.132	8.810	18.795	16.660	35.521			0.270	0.578			
65	259	UPTAKES	36.654	4.679	38.430	179.833	17.200	80.471					1.130	5.283	
66	260	PROPULS SUPPORT SYS													
67	262	MAIN PROP LUBOIL SYS	99.831	5.956	12.200	72.654			19.980	118.974	5.960	35.469			
68	264	LUBOIL FIL ,TRANS & PRF	100.000	1.055	8.900	4.389			30.580	32.266	1.160	1.221			
69	290	SPECIAL PURPOSE SYST													
70	298	PROPULS PLNT OPER FL	2.516	6.452	10.920	70.463			4.060	26.182	1.180	7.642			
71	299	PROPLN REP PRTS & TLS	0.000	2.009	19.330	38.839	34.330	68.973			0.770	1.554			
72															
73	Calculat	GROUP TOTALS		70.993	11.636	826.091	2.605	184.965	34.691	2462.822	0.830	58.954	0.079	5.641	
74	*	*Builders's Estimates*	*82.372*	*71.195*	*11.670*	*831.091*			*31.990*	*2277.857*	*0.750*	*53.312*			
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TABLE 4-1 NAVY VINDICATOR WEIGHT REPORT 3DIGWTRE.XLS Sheet 2 **AS BUILT BY TAÇOMA BOAT SHIPYARD**

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
98															
99															
100						VERTICAL	LONGITUDINAL REF TO MIDSHIP				TRANSVERSE REF TO CENTERLINE				
101					ABOVE DES BL		FORWARD		AFT		PORT		STARBOARD		
102			PERCENT	CURRENT		MOMENT		MOMENT		MOMENT		MOMENT		MOMENT	
103	GROUP	DESCRIPTION	C & A	TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	
104	300	ELECTRIC PLANT													
105	304	ELECTRIC CABLE	99.883	12.949	16.850	218.237			5.350	69.232			1.510	19.514	
106	310	ELECTRIC POWER GENER													
107	311	SHIP SERVICE PWR GEN	100.000	41.750	10.310	430.443	10.040	419.170			0.000	0.000			
108	312	EMERGENCY GENERAT	100.000	3.133	32.000	100.257	79.000	247.510					10.750	33.680	
109	313	BATT & SERV FACILITIES	72.999	0.597	34.640	20.675	73.820	44.062					5.670	3.387	
110	314	POWER CONVERS EQUIP	92.360	11.499	15.850	182.264			16.060	184.707			9.930	114.210	
111	320	PWR DISTRIB SYSTEM	98.245	1.018	21.630	22.009			5.110	5.200			3.340	3.399	
112	321	SHIP SERV PWR CABLE	0.000	5.198	34.430	178.995	15.950	82.901			2.210	11.512			
113	324	SWITCHGEAR & PANELS	99.712	15.501	17.170	266.112			4.780	74.135			0.840	13.040	
114	330	LIGHTING SYSTEM													
115	331	LIGHTING DISTRIBUTION	53.473	0.200	28.420	5.685	2.980	0.597			0.010	0.002			
116	332	LIGHTING FIXTURES	46.417	2.658	29.990	79.712	11.360	30.185			0.180	0.474			
117	390	SPECIAL PURPOSE SYST													
118	398	ELECT PLT OPER FLUIDS	0.000	0.313	33.000	10.313	81.500	25.469					10.500	3.281	
119	399	ELECL RPR PRT & SP TLS	0.000	2.411	19.000	45.804	48.330	116.518			2.110	5.079			
120															
121	Calculat	GROUP TOTALS		97.227	16.050	1560.506	9.940	966.412	3.428	333.274	0.176	17.067	42.540	190.511	
122	*	*Builder's Estimates*	*89.142*	*97.226*	*16.050*	*1560.505*	*6.510*	*633.138*					*1.780*	*173.944*	
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TABLE 4-1 NAVY VINDICATOR WEIGHT REPORT 3DIGWTRE.XLS Sheet 3 **AS BUILT BY TACOMA BOAT SHIPYARD**

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
148															
149						VERTICAL	LONGITUDINAL REF TO MIDSHIP				TRANSVERSE REF TO CENTERLINE				
150					ABOVE DES BL			FORWARD	AFT		PORT			STARBOARD	
151			PERCENT	CURRENT		MOMENT		MOMENT		MOMENT		MOMENT		MOMENT	
152	GROUP	DESCRIPTION	C & A	TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	
153	400	COMMAND & SURVEILNC													
154	410	COM & CONTR STSTEMS													
155	411	DATA DISPLA GROUP	18.605	0.038	31.260	1.200			58.450	2.244			4.340	0.167	
156	420	NAVIGATION SYSTEM													
157	421	NON-ELEC/ ELEC NAVAID	0.000	0.067	58.420	3.912	62.200	4.165			0.000	0.000			
158	422	ELECTRIC NAVAIDS	100.000	0.552	51.510	28.434			14.850	0.196	0.000	0.000			
159	423	ELECT NAV SYS, RADIO	100.000	0.075	52.660	3.938	48.900	3.656			1.760	0.132			
160	424	ELECT NAV SYS, ACOUS	100.000	0.141	0.520	0.073	44.510	6.262					3.060	0.430	
161	426	ELECTRIC NAV SYSTEM	100.000	0.992	20.320	20.149	31.890	31.624					4.940	4.897	
162	430	INTERIOR COMMUNICAT													
163	432	TELEPHONE STSTEMS	38.722	0.553	31.320	17.311			1.180	0.652			0.220	0.120	
164	433	ANNOUNCIING SYSTEMS	34.299	0.191	38.230	7.298	20.000	3.818			0.440	0.180			
165	434	ENTERTAIN & TRAIN SYS	5.954	0.255	26.560	6.771	23.600	6.017					8.310	2.118	
166	436	ALRM, SFTY, WRN SYST	53.208	0.422	27.660	11.663	11.260	4.758					0.080	0.034	
167	437	INDIC, ORDR & METR SYS	96.140	0.578	14.500	8.383			9.110	5.271	0.660	0.380			
168	440	EXTERIOR COMMUNICAT													
169	441	RADIO SYSTEM	84.340	2.512	57.340	144.056	28.730	72.172					5.450	13.681	
170	443	VISUAL & AUDIBLE SYS	0.000	0.090	55.110	4.933	64.750	5.796			0.240	0.021			
171	445	TTY & FAX SYSTEMS	100.000	0.434	42.490	18.455	49.600	21.545					9.420	4.091	
172	450	SURVEIL SYSTMS, SURF													
173	451	SURF SEARCH RADAR	71.657	0.754	57.110	43.085	59.450	44.853					1.550	1.168	
174	460	SURVEIL SYS -UNDERWT													
175	462	SURTASS ELECTRONICS	0.000	15.982	33.250	531.406			31.000	495.446	1.750	27.969			
176	490	SPEC PURPOSE SYSTMS	0.000	0.033	39.670	1.328			78.800	2.628			3.030	0.128	
177	491	ELEC TST,CHK & MON EQ	0.000	11.161	33.250	371.094			42.750	477.121	6.920	77.232			
178	499	CMD & SRV RPR PRT/TLS	0.000	0.446	22.000	9.821	68.000	30.357			1.660	0.741			
179															
180	Calculat	GROUP TOTALS		35.276	34.962	1233.310	6.662	235.023	27.882	983.558	3.023	106.655	0.761	26.834	
181	*	*Builder's Estimates*	*16.825*	*35.277*	*34.960*				*21.450*	*756.535*	*2.260*	*79.023*			
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TABLE 4-1 NAVY VINDICATOR WEIGHT REPORT 3DIGWTRE.XLS Sheet 4 **AS BUILT BY TACOMA BOAT SHIPYARD**

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
197															
198						VERTICAL	LONGITUDINAL REF TO MIDSHIP				TRANSVERSE REF TO CENTERLINE				
199					ABOVE DES BL		FORWARD		AFT		PORT		STARBOARD		
200			PERCENT	CURRENT		MOMENT		MOMENT		MOMENT		MOMENT		MOMENT	
201	GROUP	DESCRIPTION	C & A	TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	
202	500	AUXILIARY SYSTEMS													
203	503	PUMPS	100.000	3.438	8.690	29.857	3.060	10.535					2.790	9.589	
204	506	OVRFLS, AIR ESCAPES	83.842	5.272	19.890	104.889	5.420	28.557					0.810	4.270	
205	508	THERM INSUL-PP & MACH	62.195	1.417	20.800	29.472	10.580	14.992			1.340	1.905			
206	509	THRM INS -HVAC DUCTS	100.000	2.033	30.630	62.266	16.400	33.343			2.160	4.400			
207	510	CLIMATE CONTROL													
208	511	COMPART HEATNG SYS	100.000	0.559	29.760	16.640	7.170	4.009			1.690	0.946			
209	512	VENTIL SYSTEM	100.000	24.186	29.380	710.538	2.300	57.544					0.350	8.456	
210	514	AIR COND SYSTEM	96.109	12.138	18.670	226.556	20.330	249.167			9.210	111.745			
211	516	REFRIGERAT SYSTEM	99.612	0.724	16.500	11.954	46.090	33.390			10.740	7.778			
212	520	SEA WATER SYSTEMS													
213	521	FIREMAIN & FLUSH SYS	57.136	3.678	21.950	80.715			1.980	7.264	0.820	3.023			
214	524	AUXIL SW SYSTEM	100.000	3.941	10.990	43.293	10.930	43.082			0.530	2.072			
215	526	SCUPPERS & DK DRAINS	100.000	0.018	21.040	0.377	56.830	1.019					3.820	0.069	
216	528	PLUMBING DRAINAGE	66.608	9.733	22.140	215.519	10.720	104.351					1.620	15.786	
217	529	DRAIN & BALLAST SYST	100.000	5.199	8.240	42.867	0.040	0.188					2.500	13.009	
218	530	FRESH WATER SYSTEM													
219	531	DISTILLING PLANT	100.000	3.083	14.130	43.563	25.730	79.315			0.010	0.024			
220	532	COOLING WATER SYST	96.215	3.065	10.350	31.731	12.700	38.913					0.380	1.173	
221	533	POTABLE WATER SYST	62.676	2.376	21.810	51.821			6.200	14.726	1.310	3.112			
222	540	FUELS & LUBS HOLDNG													
223	541	SHIP FUEL & COMPS SYS	97.798	6.181	7.630	47.131			17.910	110.710	2.790	17.257			
224	550	AIR, GAS, MISC FL SYS													
225	551	COMPRESSED AIR SYST	94.929	3.095	11.940	36.963	7.110	22.007			1.710	5.291			
226	555	FIRE EXTINGUISH SYST	83.524	2.157	24.390	52.598			4.120	8.890			7.460	16.086	
227	556	HYDRAULIC FLUID SYS	97.458	1.063	29.010	30.834	40.990	43.573					2.370	2.517	
228	560	SHIP CONTROL SYSTMS													
229	561	STEERING CONTR SYS	100.000	2.666	17.960	47.889			96.020	256.005	0.160	0.429			
230	562	RUDDER	100.000	6.852	11.030	75.602			97.920	670.897	0.000	0.000			
231	568	MANEUVERING SYSTMS	100.000	8.684	10.280	89.305	79.000	686.066			0.940	8.179			
232	570	UNDERWY REPLEN SYS	100.000	0.786	19.470	15.303	9.730	7.645					0.320	0.252	
233	580	STERN OVERBRD SYST	0.000	11.161	27.000	301.339			109.000	1216.516	0.000	0.000			
234	581	ANCHR HNDL & STWG	100.000	18.799	24.030	451.774	82.360	1548.386			0.090	1.726			
235	582	MOORNG & TOWNG SYS	100.000	2.092	30.640	64.106	2.100	4.387			0.000	0.000			
236	583	BOAT HNDLG & STOW	67.379	1.317	40.730	53.624			25.760	33.942	3.950	5.203			
237	590	SPECIAL PURPOSE SYST													
238	591	ARRAY WINCH & ARRAY	0.000	63.839	29.000	1851.339			85.000	3426.339	0.000	0.000			
239	598	AUX SYST OPER FLUIDS	83.504	43.700	15.890	694.233			43.690	1909.070	0.310	13.668			
240	599	AUX SYS RPR PRTS, TLS	0.000	16.518	24.010	396.652			46.760	772.321			1.100	18.161	
241															
242	Calculat	GROUP TOTALS		269.770	21.910	5910.750	11.159	3010.469	31.237	8426.680	0.692	186.758	0.331	89.368	
243	*	*Builder's Estimates*	*60.142*	*269.769*	*21.910*	*5910.753*			*27.490*	*7416.215*	*0.360*	*97.386*			
244															
245															

TABLE 4-1 NAVY VINDICATOR WEIGHT REPORT 3DIGWTRE.XLS Sheet 5 **AS BUILT BY TACOMA BOAT SHIPYARD**

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
246															
247						VERTICAL	LONGITUDINAL REF TO MIDSHIP				TRANSVERSE REF TO CENTERLINE				
248					ABOVE DES BL		FORWARD		AFT		PORT		STARBOARD		
249			PERCENT	CURRENT		MOMENT		MOMENT		MOMENT		MOMENT		MOMENT	
250	GROUP	DESCRIPTION	C & A	TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	
251	600	OUTFIT & FURNISHINGS													
252	610	SHIP FITTINGS													
253	611	HULL FITTINGS	82.259	0.440	22.590	9.947			67.650	29.793	0.710	0.313			
254	612	RLS, STNCHN & LIFELNS	30.368	4.135	31.340	129.606			3.510	14.522			0.030	0.129	
255	613	RIGGING & CANVAS	0.000	0.268	47.000	12.589	17.000	4.554			0.000	0.000			
256	614	LABEL PLATES	0.000	0.335	15.000	5.022			13.000	4.353	0.000	0.000			
257	620	HULL COMPARTMNTATN													
258	621	NON-STRUCTRL BLKHDS	100.000	22.681	31.430	719.117	34.520	789.878					0.590	13.583	
259	622	FLOOR PLATES & GRTNG	71.503	17.021	21.520	366.332			41.840	712.239			0.270	4.621	
260	623	LADDERS	67.468	5.303	21.590	114.500			7.540	40.004			0.190	1.002	
261	624	NON-STRUCTR CLOSURS	80.711	5.339	28.440	151.856	24.270	129.550			0.290	1.568			
262	625	RT, FIXD PLT & WINDOWS	100.000	2.559	40.540	103.655	21.870	55.964			0.270	0.679			
263	630	PRESERVAT & COVERNG													
264	631	PAINTING	0.000	11.964	19.000	227.321	1.000	11.964			0.000	0.000			
265	633	CATHODIC PROTECTION	100.000	0.915	6.840	6.261			18.110	16.574			0.050	0.045	
266	634	DECK COVERING	15.394	7.902	26.250	207.428	19.530	154.309					0.890	7.066	
267	635	HULL INSULATION	100.000	23.165	25.620	593.539	6.690	154.921			0.020	0.566			
268	637	SHEATHING	40.765	7.041	29.280	206.144	16.800	118.267					2.070	14.548	
269	640	LIVING SPACES													
270	641	OFFCR BRTHNG & MESS	0.000	5.892	35.380	208.444	31.410	185.061					1.790	10.555	
271	642	TECHN BRTH & MESS SP	0.000	2.571	31.740	11.617	25.950	66.737			11.970	30.778			
272	643	CREW BRTH & MESS SP	0.000	5.455	24.940	136.053	13.950	76.118			4.140	22.556			
273	644	SANIT SPACES & FIXTRS	100.000	7.583	32.930	249.757	25.650	194.486			2.500	19.560			
274	645	LEISURE & COMMUN SP	70.493	0.923	23.200	21.411	47.160	43.543					5.510	5.089	
275	650	SERVICE SPACES													
276	651	COMMISARY SPACES	38.929	1.299	22.880	29.682	3.190	4.150					12.040	15.634	
277	652	MEDICAL SPACES	100.000	0.191	24.150	4.601	28.690	5.503					11.020	2.100	
278	654	UTILITY SPACES	79.121	0.641	23.990	15.391	73.700	47.279			4.110	5.643			
279	655	LAUNDRY SPACES	100.000	0.719	12.160	8.743	43.340	31.164					11.390	8.190	
280	656	TRASH DISPOS SPACES	77.519	1.440	32.150	46.293			41.560	59.833			6.900	9.920	
281	660	WORKING SPACES													
282	661	OFFICES	0.000	0.597	30.980	10.508	13.960	8.341					9.820	5.858	
283	663	ELCTR CNTR CTR FURNIS	25.157	2.374	33.740	80.108			12.160	28.873			2.740	6.592	
284	665	WRKSHP, LB, TST AREA	89.113	8.064	26.420	213.069			41.570	335.213			3.850	31.110	
285	670	STOWAGE SPACES													
286	671	LOCKRS & SPECL STORG	50.670	2.529	25.690	64.989	6.010	15.206					2.950	7.457	
287	672	STRMS & ISSU E ROOMS	52.733	6.209	24.640	152.988	60.230	373.945					0.490	3.018	
288															
289	Calculat	GROUP TOTALS		155.555	26.402	4106.971	15.885	2470.940	7.980	1241.404	0.525	81.663	0.942	146.517	
290	*	*Builder's Estimates*	*63.768*	*155.759*	*26.870*	*4185.163*	*7.890*	*1229.544*					*0.420*	*64.687*	
291	700	ARMAMENT													
292	760		0.000	0.123	50.000	6.130	15.000	1.842			0.010	0.001			
293															
294		GROUP TOTALS		0.123	50.000	6.130	15.000	1.842			0.010	0.001			

TABLE 4-1 NAVY VINDICATOR WEIGHT REPORT 3DIGWTRE.XLS Sheet 6 **AS BUILT BY TACOMA BOAT SHIPYARD**

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
295															
296						VERTICAL	LONGITUDINAL REF TO MIDSHIP				TRANSVERSE REF TO CENTERLINE				
297					ABOVE DES BL		FORWARD		AFT		PORT		STARBOARD		
298			PERCENT	CURRENT		MOMENT		MOMENT		MOMENT		MOMENT		MOMENT	
299	GROUP	DESCRIPTION	C & A	TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	
300	800	MARGINS	0.000	74.648	19.340	1443.692	0.500	37.324			0.000	0.000			
301															
302		GROUP TOTALS		74.648	19.340	1443.692	0.500	37.324			0.000	0.000			
303															
304		RUN TOTALS	79.500	1511.425	20.110	30395.656			5.170	7821.385			0.060	87.516	
305															
306		VARIABLE LOADS													
307	815	CREW & EFFECTS	0.000	5.732	31.470	160.391	19.820	113.611			4.990	28.603			
308	816	PROVISIONS	0.000	10.647	23.000	244.880	68.950	734.183					7.930	84.415	
309	817	STORES-GENERAL	0.000	6.429	12.000	205.714	95.000	610.714					2.000	12.657	
310	818	POTABLE WATER	0.000	18.573	7.560	140.362			14.600	271.143	0.000	0.000			
311	819	LUBE OIL (7.69 #/GAL)	0.000	34.485	12.150	418.987			34.630	1201.095	0.000	0.000			
312	822	FUEL OIL (6.96 #/GAL)	0.000	108.329	10.610	7513.975			3.940	2792.461	0.000	38.440			
313	824	CONTAMINATED OIL	0.000												
314	826	BALLAST	0.000	0.000	10.610	0.000			3.940	0.000	0.000	0.000			
315	827	EMERGENCY DAY TANK	0.000	0.932	34.000	31.693	77.000	71.775					10.750	10.021	
316															
317	Calculat	GROUP TOTALS		185.127	47.081	8716.002	8.266	1530.283	23.037	4264.699	0.362	67.043	0.578	107.093	
318	*	*Builder's Estimates*		** *785.125*	*11.130*	*8736.011*			*3.480*	*2734.435*			*0.500*	*40.249*	
319		RUN TOTALS			11.130	8736.011			3.480	2734.435			0.500	40.249	
320	**could	include 600 tons of fuel													
321															
322															
323															
324															
325															
326															
327															
328															
329															
330															
331															
332															

TABLE 4-1 NAVY VINDICATOR WEIGHT REPORT 3DKGWTRE.XLS Sheet 7 AS BUILT BY TACOMA BOAT SHIPYARD

the Baseline configuration mission-specific Navy hardware/equipment/outfit was removed. These "Removals" were identified by the USCG Shipyard engineering staff and the list was provided to AEL in the autumn of 1996. The Baseline Navy Configuration Light Ship weight number used as the starting point by the USCG Shipyard in 1996 is 1440.3 LT.

Ten (10) USCG weight changes are provided in the list, the largest, by far, being the removal of the Navy mission Towed Array Winch @ -29.540 LT, and the Array Winch Cable @ -34.300 LT, both within the Weight Group 591.

The seven USCG configuration Weight Estimate sheets are shown in Table 4-2, as "CGWTREP.XLS", as modified by the USCG with the Navy mission hardware removal as well as the USCG additions made to the VINDICATOR. The "deletions" are shown under the DESCRIPTION columns as initial-caps-italicized entries. The "additions" are shown as all-caps-italicized entries. The GROUP TOTALS shown at the bottom of each of the sheets of the "CGWTREP.XLS" spread sheets are only the net of the additions and deletes of each affected weight group.

As an aside, no changes were made by the USCG to the Navy VARIABLE LOADS category entries under Groups 815 through 827 even though the USCG Group 643 BERTHING MODS would permit additional crew, provisions and stores.

Significantly, also, the USCG Shipyard-provided VINDICATOR weight estimate does not account for any ballast change (Group 829) to longitudinally re-trim the ship fore-aft to account for the substantial weight reduction at the stern which was caused by the removal of the Group 580 ARRAY FAIRLEAD, the Group 591 ARRAY WINCH and the Group 591 TOWED ARRAY CABLE, a total deletion of 68.30 LT aft.

The sheet 7 of the USCG Configuration "CGWTREP.XLS" spread sheets shows the USCG VINDICATOR Light Ship change or "delta" summary of 1365.34 LT or a net reduction from the Navy T-AGOS configuration Light Ship of 1440.30 LT of -74.96 LT. The individual deletions total 94.63 LT and the additions total 19.67 LT. Therefore, the net percentage change in the Light Ship weights, from the Navy to the USCG configuration, is a reduction of 5.2%.

4.3.2.2. Diesel Engined to Fuel Cell Powered Changes

Starting with the Group 162 STACKS AND MACKS, the twin stacks are removed, as was shown in Figures 3-9, 3-10 and 3-11, because they are no longer needed. The deletion accounts for an estimated 5.903 LT. The addition of an estimated 1 LT to accounts for the deck cover plates over the stack openings, added railings as well as the 12 new aft-facing shrouded vent openings, previously discussed in Section 3.9. The total Group 162 reduction is thus 4.903 LT.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1						VERTICAL	LONGITUDINAL REF TO MIDSHIP				TRANSVERSE REF TO CENTERLINE				*NOTES*
2					ABOVE DES BL		FORWARD		AFT		PORT		STARBOARD		
3			PERCENT	CURRENT		MOMENT		MOMENT		MOMENT		MOMENT		MOMENT	
4	GROUP	DESCRIPTION	C & A	TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	
5	100	GEN HULL STRUCT													
6	110	SHELL & SUPP STRUC													
7	111	HULL SHELL PLATING													
8	113	INNER BOTTOM													
9	114	SHELL APPENDAGES													
10	115	STANCHIONS													
11	116	HULL LONG FRAMING													
12	117	HULL TRANSV FRAM													
13	120	HULL STRUCT BHDS													
14	121	LONG STRUCT BHDS													
15	122	TRANSVERS STR BHDS													
16	123	TRUNKS & ENCLOS													
17	130	HULL DECKS													
18	131	MAIN HULL													
19	134	4TH DK HOLD-HOLD DK													
20	136	01 LEVEL-FOC'SLE DK													
21	137	02 LEVEL-UPPER DK													
22	138	03 LEVEL-BRIDGE DECK													
23	140	HULL PLAT & FLATS													
24	141	1ST PLATFORM													
25	150	DK HOUS STRUCTURES													
26	150	WINCH CONTROL STATN		*9.560*	*35.230*	*336.799*			*75.650*	*723.214*					*Delete*
27	151	01 LEV DKHS STRUCT													
28	152	02 LEV DKHS STRUCT													
29	153	03 LEV DKHS STRUCT													
30	154	04 LEV DKHS STRUCT													
31	160	SPECIAL STRUCTURES													
32	161	STRL CAST, FORG, WLD													
33	162	STACKS & MACKS													
34	163	SEA CHESTS													
35	167	HULL STRUCT CLOSURS													
36	168	DECKHS STRUCT CLOS													
37	170	MASTS													
38	171	MASTS, TWRS, TETRAP													
39	180	FOUNDATIONS													
40	182	PROP PLANT FOUNDAT													
41	183	ELECTRIC FOUNDATNS													
42	184	COMMND & SURV FDNS													
43	185	AUX SYSTEM FDNS													
44	186	OUTFIT & FURNISH FDNS													
45	190	SPECIAL PURPOSE SYST													
46	197	WELDMENT													
47	198	FREE FLOODING LIQUIDS													
48	199	HULL REP PRTS & SP TLS													
49															
50	Calculat	*Group Total Deletes*		*9.560*	*35.230*	*336.799*			*75.650*	*723.214*					*Delete*

TABLE 4-2 USCG VINDICATOR WT REPORT CGWTREP.XLS Sheet 1 **AS MODIFIED BY USCG (NAVY MISSION HARDWARE REMOVED)**

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
51						VERTICAL	LONGITUDINAL REF TO MIDSHIP				TRANSVERSE REF TO CENTERLINE				*NOTES*
52					ABOVE DES BL			FORWARD	AFT		PORT			STARBOARD	
53			PERCENT	CURRENT		MOMENT		MOMENT		MOMENT		MOMENT		MOMENT	
54	GROUP	DESCRIPTION	C & A	TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	
55	200	PROPULSION PLANT													
56	230	PROPULSION UNITS													
57	235	ELECTRIC PROPULSION													
58	240	TRANS & PROPULS SYST													
59	243	PROPULSION SHAFTING													
60	244	PROPUL SHAF BEARNGS													
61	245	PROPULSORS													
62	250	PROPULSION SUPP SYST													
63	252	PROPULSION CONT SYST													
64	256	CRCLT & CLNG SW SYST													
65	259	UPTAKES													
66	260	PROPULS SUPPORT SYS													
67	262	MAIN PROP LUBOIL SYS													
68	264	LUBOIL FIL ,TRANS & PRF													
69	290	SPECIAL PURPOSE SYST													
70	298	PROPULS PLNT OPER FL													
71	299	PROPLN REP PRTS & TLS													
72															
73	Calculat	*Group Total Deletes*	*(None)*												
74															
75															
76															
77															
78															
79															
80															
81															
82															
83															
84															
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89															
90															
91															
92															
93															
94															
95															
96															
97															

TABLE 4-2 USCG VINDICATOR WT REPORT CGWTREP.XLS Sheet 2 **AS MODIFIED BY USCG (NAVY MISSION HARDWARE REMOVED)**

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
98															
99															
100						VERTICAL	LONGITUDINAL REF TO MIDSHIP				TRANSVERSE REF TO CENTERLINE				*NOTES*
101					ABOVE DES BL		FORWARD		AFT		PORT		STARBOARD		
102			PERCENT	CURRENT		MOMENT		MOMENT		MOMENT		MOMENT		MOMENT	
103	GROUP	DESCRIPTION	C & A	TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	
104	300	ELECTRIC PLANT													
105	304	ELECTRIC CABLE													
106	310	ELECTRIC POWER GENER													
107	311	SHIP SERVICE PWR GEN													
108	312	EMERGENCY GENERAT													
109	313	BATT & SERV FACILITIES													
110	314	POWER CONVERS EQUIP													
111	320	PWR DISTRIB SYSTEM													
112	321	SHIP SERV PWR CABLE													
113	324	SWITCHGEAR & PANELS													
114	330	LIGHTING SYSTEM													
115	331	LIGHTING DISTRIBUTION													
116	332	LIGHTING FIXTURES													
117	390	SPECIAL PURPOSE SYST													
118	398	ELECT PLT OPER FLUIDS													
119	399	ELECL RPR PRT & SP TLS													
120															
121	Calculat	***Group Total Deletes***	*(None)*												
122															
123															
124															
125															
126															
127															
128															
129															
130															
131															
132															
133															
134															
135															
136															
137															
138															
139															
140															
141															
142															
143															
144															
145															
146															
147															

TABLE 4-2 USCG VINDICATOR WT REPORT CGWTREP.XLS Sheet 3 **AS MODIFIED BY USCG (NAVY MISSION HARDWARE REMOVED)**

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
148															
149						VERTICAL	LONGITUDINAL REF TO MIDSHIP				TRANSVERSE REF TO CENTERLINE				*NOTES*
150					ABOVE DES BL			FORWARD	AFT		PORT			STARBOARD	
151			PERCENT	CURRENT		MOMENT		MOMENT		MOMENT		MOMENT		MOMENT	
152	GROUP	DESCRIPTION	C & A	TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	
153	400	COMMAND & SURVEILNC													
154	410	COM & CONTR STSTEMS													
155	411	DATA DISPLA GROUP													
156	420	NAVIGATION SYSTEM													
157	421	NON-ELEC/ ELEC NAVAID													
158	422	ELECTRIC NAVAIDS													
159	423	ELECT NAV SYS, RADIO													
160	424	ELECT NAV SYS, ACOUS													
161	426	ELECTRIC NAV SYSTEM													
162	430	INTERIOR COMMUNICAT													
163	432	TELEPHONE STSTEMS													
164	433	ANNOUNCIING SYSTEMS													
165	434	ENTERTAIN & TRAIN SYS													
166	436	ALRM, SFTY, WRN SYST													
167	437	INDIC, ORDR & METR SYS													
168	440	EXTERIOR COMMUNICAT													
169	441	RADIO SYSTEM													
170	443	VISUAL & AUDIBLE SYS													
171	445	TTY & FAX SYSTEMS													
172	450	SURVEIL SYSTMS, SURF													
173	451	SURF SEARCH RADAR													
174	460	SURVEIL SYS -UNDERWT													
175	462	SURTASS ELECTRONICS		*15.982*	*33.250*	*531.402*			*31.000*	*495.442*	*1.750*	*27.969*			*Delete*
176	490	SPEC PURPOSE SYSTMS													
177	491	ELEC TST,CHK & MON EQ													
178	499	CMD & SRV RPR PRT/TLS													
179															
180	Calculat	***Group Total Deletes***		*15.982*	*33.250*	*531.402*			*31.000*	*495.442*	*1.750*	*27.969*			*Delete*
181															
182															
183															
184															
185															
186															
187															
188															
189															
190															
191															
192															
193															
194															

TABLE 4-2 USCG VINDICATOR WT REPORT CGWTREP.XLS Sheet 4 **AS MODIFIED BY USCG (NAVY MISSION HARDWARE REMOVED)**

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
195															
196						VERTICAL	LONGITUDINAL REF TO MIDSHIP				TRANSVERSE REF TO CENTERLINE				*NOTES*
197					ABOVE DES BL			FORWARD	AFT		PORT			STARBOARD	
198			PERCENT	CURRENT		MOMENT		MOMENT		MOMENT		MOMENT		MOMENT	
199	GROUP	DESCRIPTION	C & A	TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	
200	500	AUXILIARY SYSTEMS													
201	503	PUMPS													
202	506	OVRFLS, AIR ESCAPES													
203	508	THERM INSUL-PP & MACH													
204	509	THRM INS -HVAC DUCTS													
205	510	CLIMATE CONTROL													
206	511	COMPART HEATNG SYS													
207	512	VENTIL SYSTEM													
208	514	AIR COND SYSTEM													
209	516	REFRIGERAT SYSTEM													
210	520	SEA WATER SYSTEMS													
211	521	FIREMAIN & FLUSH SYS													
212	524	AUXIL SW SYSTEM													
213	526	SCUPPERS & DK DRAINS													
214	528	PLUMBING DRAINAGE													
215	529	DRAIN & BALLAST SYST													
216	530	FRESH WATER SYSTEM													
217	531	DISTILLING PLANT													
218	532	COOLING WATER SYST													
219	533	POTABLE WATER SYST													
220	540	FUELS & LUBS HOLDNG													
221	541	SHIP FUEL & COMPS SYS													
222	550	AIR, GAS, MISC FL SYS													
223	551	COMPRESSED AIR SYST													
224	555	FIRE EXTINGUISH SYST													
225	556	HYDRAULIC FLUID SYS													
226	560	SHIP CONTROL SYSTMS													
227	561	STEERING CONTR SYS													
228	562	RUDDER													
229	568	MANEUVERING SYSTMS													
230	570	UNDERWY REPLEN SYS													
231	580	STERN OVERBRD SYST	*Arr Fairld*	*4.460*	*24.500*	*109.270*			*105.000*	*468.300*					*Delete*
232	581	ANCHR HNDL & STWG													
233	582	BOAT HNDLG & STOW	*Rescue B*	*0.790*	*40.870*	*32.287*			*27.580*	*21.788*					*ADD*
234	583	RHI INSTALLATION	*USCG EQ*	*7.720*	*37.170*	*286.952*			*26.380*	*203.654*					*ADD*
235	583	LIFE RAFTS	*USCG EQ*	*5.580*	*40.830*	*227.831*			*37.000*	*206.460*					*ADD*
236	590	SPECIAL PURPOSE SYST													
237	591	ARRAY WINCH & ARRAY	*Surtass*	*29.540*	*29.000*	*856.660*			*83.500*	*2466.590*					*Delete*
238	591	ARRAY WINCH CABLE	*Surtass*	*34.300*	*29.000*	*994.700*			*86.290*	*2959.747*					*Delete*
239	598	AUX SYST OPER FLUIDS													
240	599	AUX SYS RPR PRTS, TLS													
241															
242	Calculat	***Group Total Deletes***		*82.390*	*30.437*	*2507.701*			*76.788*	*6326.539*					*Delete*
243		***GROUP TOTAL ADDS***		*13.300*	*41.133*	*547.071*			*32.474*	*431.902*					*ADD*
244		***Group Delete Total***		*69.090*	*28.378*	*1960.630*			*85.318*	*5894.637*					*Delete*

TABLE 4-2 USCG VINDICATOR WT REPORT CGWTREP.XLS Sheet 5 AS MODIFIED BY USCG (NAVY MISSION HARDWARE REMOVED)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
245															
246						VERTICAL	LONGITUDINAL REF TO MIDSHIP				TRANSVERSE REF TO CENTERLINE				*NOTES*
247					ABOVE DES BL			FORWARD	AFT		PORT			STARBOARD	
248			PERCENT	CURRENT		MOMENT		MOMENT		MOMENT		MOMENT		MOMENT	
249	GROUP	DESCRIPTION	C & A	TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	
250	600	OUTFIT & FURNISHINGS													
251	610	SHIP FITTINGS													
252	611	HULL FITTINGS													
253	611	TOWING BITT		*3.200*	*22.080*	*70.656*			*84.000*	*268.800*					*ADD*
254	612	RLS, STNCHN & LIFELNS													
255	613	RIGGING & CANVAS													
256	614	LABEL PLATES													
257	620	HULL COMPARTMNTATN													
258	621	NON-STRUCTRL BLKHDS													
259	622	FLOOR PLATES & GRTNG													
260	623	LADDERS													
261	624	NON-STRUCTR CLOSURS													
262	625	RT, FIXD PLT & WINDOWS													
263	630	PRESERVAT & COVERNG													
264	631	PAINTING													
265	633	CATHODIC PROTECTION													
266	634	DECK COVERING													
267	635	HULL INSULATION													
268	637	SHEATHING													
269	640	LIVING SPACES													
270	641	OFFCR BRTHNG & MESS													
271	642	TECHN BRTH & MESS SP													
272	643	CREW BRTH & MESS SP		*3.170*	*31.740*	*100.616*	*19.000*	*60.230*							*ADD*
273	644	SANIT SPACES & FIXTRS													
274	645	LEISURE & COMMUN SP													
275	650	SERVICE SPACES													
276	651	COMMISARY SPACES													
277	652	MEDICAL SPACES													
278	654	UTILITY SPACES													
279	655	LAUNDRY SPACES													
280	656	TRASH DISPOS SPACES													
281	660	WORKING SPACES													
282	661	OFFICES													
283	663	ELCTR CNTR CTR FURNIS													
284	665	WRKSHP, LB, TST AREA													
285	670	STOWAGE SPACES													
286	671	LOCKRS & SPECL STORG													
287	672	STRMS & ISSUE ROOMS													
288															
289	Calculat	*GROUP TOTAL ADDS*		*6.370*	*26.887*	*171.272*	*19.000*	*60.230*	*84.000*	*268.800*					*ADD*
290															
291	700	ARMAMENT													
292	760														
293															

TABLE 4-2 USCG VINDICATOR WT REPORT CGWTREP.XLS Sheet 6 **AS MODIFIED BY USCG (NAVY MISSION HARDWARE REMOVED)**

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
294															
295						VERTICAL		LONGITUDINAL REF TO MIDSHIP			TRANSVERSE REF TO CENTERLINE				*NOTES*
296					ABOVE DES BL			FORWARD	AFT		PORT			STARBOARD	
297			PERCENT	CURRENT		MOMENT		MOMENT		MOMENT		MOMENT		MOMENT	
298	GROUP	DESCRIPTION	C & A	TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	
299	800	MARGINS													
300															
301		**GROUP TOTALS**													
302															
303		**RUN TOTALS**													
304															
305		VARIABLE LOADS													
306	815	CREW & EFFECTS													
307	816	PROVISIONS													
308	817	STORES-GENERAL													
309	818	POTABLE WATER													
310	819	LUBE OIL (7.69 #/GAL)													
311	822	FUEL OIL (6.96 #/GAL)													
312	824	CONTAMINATED OIL													
313	826	BALLAST													
314	827	EMERGENCY DAY TANK													
315															
316	Calculat	*NAVY LIGHT SHIP*		1440.300											PER USCG
317		***Total Deletes***		*94.632*											
318		*TOTAL ADDS*		*19.670*											
319		***Net Reduction***		*74.962*											
320		*USCG LIGHT SHIP*		1365.338											PER USCG
321															
322															
323															
324															
325															
326															
327															
328															
329															
330															
331															
332															

TABLE 4-2 USCG VINDICATOR WT REPORT CGWTREP.XLS Sheet 7 **AS MODIFIED BY USCG (NAVY MISSION HARDWARE REMOVED)**

The weight comparison information which cover the new configuration wherein the diesel engined VINDICATOR configuration is changed over to the fuel cell powered configuration is summarized in the seven sheets of the "FCVWTREP.XLS" spread sheets shown in Table 4-3, titled as FUEL CELL POWERED USCG DEMONSTRATION SHIP. Some of the weight deletions and additions to the various weight groups are quite precise while others are estimated within the context of the feasibility study level of effort. The accuracy of all the weight group numbers will improve substantially once the ship preliminary design is underway.

The next major weight deletion is to the Group 183 ELECTRICAL FOUNDATIONS which are the nearly 33 LT of the sound isolating bedplates or "rafts" below the four diesel electric generators in the "engine room" space. Because some structural decking will remain the deletion is made for an estimated 29.625 LT of the above weight. Figure 4-7 shows an inboard profile elevation view of the structural decking and the current diesel generators mounted on their sound isolation bedplates. Once the bedplates, the catwalks and steps between the engine generators as well as the decking fore and aft of the engine spaces have been removed the elevation view is shown in Figure 4-8 with a 15 ft 8 inch longitudinal space is seen. Further decking is then removed to allow for the 20 ft 4 inch fore-aft space needed for the four rows of fuel cell modules (see Figure 3-7) before the structural and decking additions to the space (to accommodate the fuel cells) can be considered.

It is worth noting that these AUTOCAD type computer drawings, taken from the USCG Shipyard's scanned paper copies of 1983 vintage ship drawings, needed to be "cleaned up" due to scanning inaccuracies and orthogonal distortions before they could be scaled to architectural units (ft and inches) and then made into the accurate explanatory Figures such as 4-7, 4-8 and 3-7 as referred to above. It looks easy, but in fact, it involves many hours of careful AUTOCAD-witting engineering work.

The next important weight deletion which occurs with the removal of the diesel electric generation system is the deletion of most of the 4.679 LT of the Group 259 UPTAKES. This group includes the exhaust ducting from the four diesel engines plus their four exhaust silencers (two silencers in the port stack and two in the starboard stack). Fuel cells require no silencing but will still require exhaust ducting. Therefore, a deletion of 3.743 LT is made from Group 259.

The next deletion, which occurs when the diesel engine generator system is removed, involves the Group 262 MAIN PROPULSION LUBOIL SYSTEM. While the lubrication system is still needed for the bearings of the two main propulsion motors aft, the full lubrication system weight 5.956 LT is no longer needed. The reduction in the size of this system represents a deletion of 5.36 LT of weight.

The next deletion is the Group 304 ELECTRIC CABLE with which the AC output diesel electric generators are connected to the electric power conditioning equipment. The baseline 12.949 LT of electrical cable weight is reduced to 9.064 LT.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1						VERTICAL	LONGITUDINAL REF TO MIDSHIP				TRANSVERSE REF TO CENTERLINE				*NOTES*
2					ABOVE DES BL		FORWARD		AFT		PORT		STARBOARD		
3			PERCENT	CURRENT		MOMENT		MOMENT		MOMENT		MOMENT		MOMENT	
4	GROUP	DESCRIPTION	C & A	TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	
5	100	GEN HULL STRUCT													
6	110	SHELL & SUPP STRUC													
7	111	HULL SHELL PLATING													
8	113	INNER BOTTOM													
9	114	SHELL APPENDAGES													
10	115	STANCHIONS													
11	116	HULL LONG FRAMING													
12	117	HULL TRANSV FRAM													
13	120	HULL STRUCT BHDS													
14	121	LONG STRUCT BHDS													
15	122	TRANSVERS STR BHDS													
16	123	TRUNKS & ENCLOS													
17	130	HULL DECKS													
18	131	MAIN HULL													
19	134	4TH DK HOLD-HOLD DK													
20	136	01 LEVEL-FOC'SLE DK													
21	137	02 LEVEL-UPPER DK													
22	138	03 LEVEL-BRIDGE DECK													
23	140	HULL PLAT & FLATS													
24	141	1ST PLATFORM													
25	150	DK HOUS STRUCTURES													
26	151	01 LEV DKHS STRUCT													
27	152	02 LEV DKHS STRUCT													
28	153	03 LEV DKHS STRUCT													
29	154	04 LEV DKHS STRUCT													
30	160	SPECIAL STRUCTURES													
31	161	STRL CAST, FORG, WLD													
32	162	STACKS & MACKS	*2 Stacks*	*4.903*	*55.900*	*274.078*	*13.430*	*65.847*							*Delete*
33	163	SEA CHESTS													
34	167	HULL STRUCT CLOSURS													
35	168	DECKHS STRUCT CLOS													
36	171	MASTS, TWRS, TETRAP													
37	180	FOUNDATIONS													
38	182	PROP PLANT FOUNDAT													
39	183	ELECTRIC FOUNDATNS	*2 Bedplts*	*29.625*	*7.250*	*214.781*	*9.610*	*284.696*			*0.630*	*18.664*	*0.630*	*18.664*	*Delete*
40	183	FUEL CELL FOUNDATION	*12 MOD*	*14.964*	*7.250*	*108.489*	*9.610*	*143.804*							*ADD*
41	184	COMMND & SURV FDNS													
42	185	AUX SYSTEM FDNS													
43	186	OUTFIT & FURNISH FDNS													
44	190	SPECIAL PURPOSE SYST													
45	197	WELDMENT													
46	198	FREE FLOODING LIQUIDS													
47	199	HULL REP PRTS & SP TLS													
48															
49	Calculat	*Group Total Deletes*		*34.528*	*14.158*	*488.859*	*10.152*	*350.544*			*0.630*	*18.664*	*0.630*	*18.664*	*Delete*
50		*GROUP TOTAL ADDS*		*14.964*	*7.250*	*108.489*	*9.610*	*143.804*							*ADD*

TABLE 4-3 FC VINDICATOR WEIGHT REPORT FCVWTREP.XLS Sheet 1 **AS FUEL CELL POWERED USCG DEMONSTRATION SHIP**

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
51						VERTICAL	LONGITUDINAL REF TO MIDSHIP				TRANSVERSE REF TO CENTERLINE				*NOTES*
52					ABOVE DES BL			FORWARD	AFT		PORT			STARBOARD	
53			PERCENT	CURRENT		MOMENT		MOMENT		MOMENT		MOMENT		MOMENT	
54	GROUP	DESCRIPTION	C & A	TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	
55	200	PROPULSION PLANT													
56	230	PROPULSION UNITS													
57	235	ELECTRIC PROPULSION													
58	240	TRANS & PROPULS SYST													
59	243	PROPULSION SHAFTING													
60	244	PROPUL SHAF BEARNGS													
61	245	PROPULSORS													
62	250	PROPULSION SUPP SYST													
63	252	PROPULSION CONT SYST													
64	256	CRCLT & CLNG SW SYST													
65	259	UPTAKES	*2 Stacks*	*3.743*	*38.430*	*143.843*	*17.200*	*64.380*							*Delete*
66	259	FC INTAKE SALT AIR REM	*1 INTAKE*	*0.500*	*25.000*	*12.500*	*17.200*	*8.600*							*ADD*
67	260	PROPULS SUPPORT SYS													
68	262	MAIN PROP LUBOIL SYS													
69	264	LUBOIL FIL,TRANS & PRF	*DGs only*	*5.360*	*12.200*	*65.392*	*8.240*	*44.166*							*Delete*
70	290	SPECIAL PURPOSE SYST													
71	298	PROPULS PLNT OPER FL													
72	299	PROPLN REP PRTS & TLS													
73															
74	Calculat	***Group Total Deletes***		*9.603*	*23.090*	*221.735*	*12.199*	*117.146*							*Delete*
75		***GROUP TOTAL ADDS***		*0.500*	*25.000*	*12.500*	*17.200*	*8.600*							ADD
76															
77															
78															
79															
80															
81															
82															
83															
84															
85															
86															
87															
88															
89															
90															
91															
92															
93															
94															
95															
96															
97															

TABLE 4-3 FC VINDICATOR WEIGHT REPORT FCVWTREP.XLS Sheet 2 **AS FUEL CELL POWERED, USCG DEMONSTRATION SHIP**

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
98															
99															
100						VERTICAL	LONGITUDINAL REF TO MIDSHIP				TRANSVERSE REF TO CENTERLINE				*NOTES*
101					ABOVE DES BL		FORWARD		AFT		PORT		STARBOARD		
102			PERCENT	CURRENT		MOMENT		MOMENT		MOMENT		MOMENT		MOMENT	
103	GROUP	DESCRIPTION	C & A	TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	
104	300	ELECTRIC PLANT													
105	304	DG ELECTRIC CABLE	*AC*	*9.064*	*16.850*	*152.728*			*5.350*	*48.492*			*1.510*	*13.687*	*Delete*
106	304	FC ELECTRIC CABLE	*DC*	*12.000*	*16.000*	*192.000*			*5.000*	*60.000*			*1.500*	*18.000*	*ADD*
107	310	ELECTRIC POWER GENER		*39.663*	*10.310*	*408.926*	*10.040*	*398.217*							*Delete*
108	310	FC POWER MODULES	*12 MOD*	*67.800*	*5.000*	*339.000*	*10.000*	*678.000*							*ADD*
109	311	SHIP SERVICE PWR GEN													
110	312	EMERGENCY GENERAT													
111	313	BATT & SERV FACILITIES													
112	314	POWER CONVERS EQUIP	*Less Req*	*10.924*	*15.850*	*173.145*	*16.060*	*175.439*					*9.930*	*108.475*	*Delete*
113	320	PWR DISTRIB SYSTEM													
114	321	SHIP SERV PWR CABLE													
115	324	SWITCHGEAR & PANELS	*Less Req*	*13.951*	*17.170*	*239.539*			*4.780*	*66.686*			*0.840*	*11.719*	*Delete*
116	324	FC MOD SWITCHGEAR	*DC*	*17.862*	*17.000*	*303.654*			*5.000*	*89.310*			*1.000*	*17.862*	*ADD*
117	330	LIGHTING SYSTEM													
118	331	LIGHTING DISTRIBUTION													
119	332	LIGHTING FIXTURES													
120	390	SPECIAL PURPOSE SYST													
121	398	ELECT PLT OPER FLUIDS													
122	399	ELECL RPR PRT & SP TLS													
123															
124	Calculat	*Group Total Deletes*		*73.602*	*13.238*	*974.338*	*7.794*	*573.656*	*1.566*	*115.178*			*1.820*	*133.881*	*Delete*
125		*GROUP TOTAL ADDS*		*97.662*	*8.546*	*834.654*	*6.942*	*678.000*	*1.529*	*149.310*			*0.367*	*35.862*	*ADD*
126															
127															
128															
129															
130															
131															
132															
133															
134															
135															
136															
137															
138															
139															
140															
141															
142															
143															
144															
145															
146															
147															

TABLE 4-3 FC VINDICATOR WEIGHT REPORT FCVWTREP.XLS Sheet 3 **AS FUEL CELL POWERED USCG DEMONSTRATION SHIP**

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
148															
149						VERTICAL	LONGITUDINAL REF TO MIDSHIP				TRANSVERSE REF TO CENTERLINE				*NOTES*
150					ABOVE DES BL			FORWARD	AFT		PORT			STARBOARD	
151			PERCENT	CURRENT		MOMENT		MOMENT		MOMENT		MOMENT		MOMENT	
152	GROUP	DESCRIPTION	C & A	TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	
153	400	COMMAND & SURVEILNC													
154	410	COM & CONTR STSTEMS													
155	411	DATA DISPLA GROUP													
156	420	NAVIGATION SYSTEM													
157	421	NON-ELEC/ ELEC NAVAID													
158	422	ELECTRIC NAVAIDS													
159	423	ELECT NAV SYS, RADIO													
160	424	ELECT NAV SYS, ACOUS													
161	426	ELECTRIC NAV SYSTEM													
162	430	INTERIOR COMMUNICAT													
163	432	TELEPHONE STSTEMS													
164	433	ANNOUNCIING SYSTEMS													
165	434	ENTERTAIN & TRAIN SYS													
166	436	ALRM, SFTY, WRN SYST													
167	437	INDIC, ORDR & METR SYS													
168	440	EXTERIOR COMMUNICAT													
169	441	RADIO SYSTEM													
170	443	VISUAL & AUDIBLE SYS													
171	445	TTY & FAX SYSTEMS													
172	450	SURVEIL SYSTMS, SURF													
173	451	SURF SEARCH RADAR													
174	460	SURVEIL SYS -UNDERWT													
175	462	SURTASS ELECTRONICS													
176	490	SPEC PURPOSE SYSTMS													
177	491	ELEC TST,CHK & MON EQ		*10.603*	*33.250*	*352.550*			*42.750*	*453.278*	*6.920*	*73.373*			*Delete*
178	499	CMD & SRV RPR PRT/TLS													
179															
180	Calculat	***Group Total Deletes***		*10.603*	*33.250*	*352.550*			*42.750*	*453.278*	*6.920*	*73.373*			*Delete*
181															
182															
183															
184															
185															
186															
187															
188															
189															
190															
191															
192															
193															
194															
195															
196															

TABLE 4-3 FC VINDICATOR WEIGHT REPORT FCVWTREP.XLS Sheet 4 **AS FUEL CELL POWERED USCG DEMONSTRATION SHIP**

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
197															
198						VERTICAL	LONGITUDINAL REF TO MIDSHIP				TRANSVERSE REF TO CENTERLINE				*NOTES*
199					ABOVE DES BL			FORWARD	AFT		PORT			STARBOARD	
200			PERCENT	CURRENT		MOMENT		MOMENT		MOMENT		MOMENT		MOMENT	
201	GROUP	DESCRIPTION	C & A	TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	
202	500	AUXILIARY SYSTEMS													
203	503	PUMPS													
204	506	OVRFLS, AIR ESCAPES													
205	508	THERM INSUL-PP & MACH													
206	509	THRM INS -HVAC DUCTS													
207	510	CLIMATE CONTROL													
208	511	COMPART HEATNG SYS													
209	512	VENTIL SYSTEM													
210	514	AIR COND SYSTEM													
211	516	REFRIGERAT SYSTEM													
212	520	SEA WATER SYSTEMS													
213	521	FIREMAIN & FLUSH SYS													
214	524	AUXIL SW SYSTEM													
215	526	SCUPPERS & DK DRAINS													
216	528	PLUMBING DRAINAGE													
217	529	DRAIN & BALLAST SYST													
218	530	FRESH WATER SYSTEM													
219	531	DISTILLING PLANT													
220	532	COOLING WATER SYST													
221	533	POTABLE WATER SYST													
222	540	FUELS & LUBS HOLDNG													
223	541	SHIP FUEL & COMPS SYS													
224	550	AIR, GAS, MISC FL SYS													
225	551	COMPRESSED AIR SYST													
226	555	FIRE EXTINGUISH SYST													
227	556	HYDRAULIC FLUID SYS													
228	560	SHIP CONTROL SYSTMS													
229	561	STEERING CONTR SYS													
230	562	RUDDER													
231	568	MANEUVERING SYSTMS													
232	570	UNDERWY REPLEN SYS													
233	580	STERN OVERBRD SYST													
234	581	ANCHR HNDL & STWG													
235	582	MOORNG & TOWNG SYS													
236	583	BOAT HNDLG & STOW													
237	590	SPECIAL PURPOSE SYST													
238	591	ARRAY WINCH & ARRAY													
239	598	AUX SYST OPER FLUIDS													
240	599	AUX SYS RPR PRTS, TLS													
241															
242	Calculat	*Group Deletes/ADDS*	*None*												
243															
244															
245															

TABLE 4-3 FC VINDICATOR WEIGHT REPORT FCVWTREP.XLS Sheet 5 AS FUEL CELL POWERED USCG DEMONSTRATION SHIP

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
246															
247						VERTICAL	LONGITUDINAL REF TO MIDSHIP				TRANSVERSE REF TO CENTERLINE				*NOTES*
248					ABOVE DES BL			FORWARD	AFT		PORT			STARBOARD	
249			PERCENT	CURRENT		MOMENT		MOMENT		MOMENT		MOMENT		MOMENT	
250	GROUP	DESCRIPTION	C & A	TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	
251	600	OUTFIT & FURNISHINGS													
252	610	SHIP FITTINGS													
253	611	HULL FITTINGS													
254	612	RLS, STNCHN & LIFELNS													
255	613	RIGGING & CANVAS													
256	614	LABEL PLATES													
257	620	HULL COMPARTMNTATN													
258	621	NON-STRUCTRL BLKHDS													
259	622	FLOOR PLATES & GRTNG													
260	623	LADDERS													
261	624	NON-STRUCTR CLOSURS													
262	625	RT, FIXD PLT & WINDOWS													
263	630	PRESERVAT & COVERNG													
264	631	PAINTING													
265	633	CATHODIC PROTECTION													
266	634	DECK COVERING													
267	635	HULL INSULATION													
268	637	SHEATHING													
269	640	LIVING SPACES													
270	641	OFFCR BRTHNG & MESS													
271	642	TECHN BRTH & MESS SP													
272	643	CREW BRTH & MESS SP													
273	644	SANIT SPACES & FIXTRS													
274	645	LEISURE & COMMUN SP													
275	650	SERVICE SPACES													
276	651	COMMISARY SPACES													
277	652	MEDICAL SPACES													
278	654	UTILITY SPACES													
279	655	LAUNDRY SPACES													
280	656	TRASH DISPOS SPACES													
281	660	WORKING SPACES													
282	661	OFFICES													
283	663	ELCTR CNTR CTR FURNIS													
284	665	WRKSHP, LB, TST AREA													
285	670	STOWAGE SPACES													
286	671	LOCKRS & SPECL STORG													
287	672	STRMS & ISSU E ROOMS													
288															
289	Calculat	*Group Deletes/ADDS*	*None*												
290															
291	700	ARMAMENT													
292	760														
293															
294															

TABLE 4-3 FC VINDICATOR WEIGHT REPORT FCVWTREP.XLS Sheet 6 **AS FUEL CELL POWERED,USCG DEMONSTRATION SHIP**

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
295															
296						VERTICAL	LONGITUDINAL REF TO MIDSHIP				TRANSVERSE REF TO CENTERLINE				*NOTES*
297					ABOVE DES BL			FORWARD	AFT		PORT			STARBOARD	
298			PERCENT	CURRENT		MOMENT		MOMENT		MOMENT		MOMENT		MOMENT	
299	GROUP	DESCRIPTION	C & A	TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	ARM FT	FT-TONS	
300	800	MARGINS													
301															
302															
303															
304															
305															
306															
307	815	CREW & EFFECTS													
308	816	PROVISIONS													
309	817	STORES-GENERAL													
310	818	POTABLE WATER													
311	819	LUBE OIL (7.69 #/GAL)													
312	822	FUEL OIL (6.96 #/GAL)													
313	824	CONTAMINATED OIL													
314	826	BALLAST													
315	827	EMERGENCY DAY TANK													
316															
317	Calculat	*Group Deletes/ADDS*	*None*												
318															
319															
320		*USCG LIGHT SHIP*		1365.338											PER USCG
321		*Total Deletes*		*127.863*											
322		*TOTAL ADDS*		*113.126*											
323		*Net Reduction*		*14.710*											
324		*FC POWERED LIGHT SHIP*		1350.628											
325															
326															
327															
328															
329															
330															
331															
332															
333															

TABLE 4-3 FC VINDICATOR WEIGHT REPORT FCVWTREP.XLS Sheet 7 **AS FUEL CELL POWERED USCG DEMONSTRATION SHIP**

FIGURE 4-7 ELEVATION VIEW SHOWING DIESEL ENGINE GENERATORS AND SOUND-ISOLATION BEDPLATES

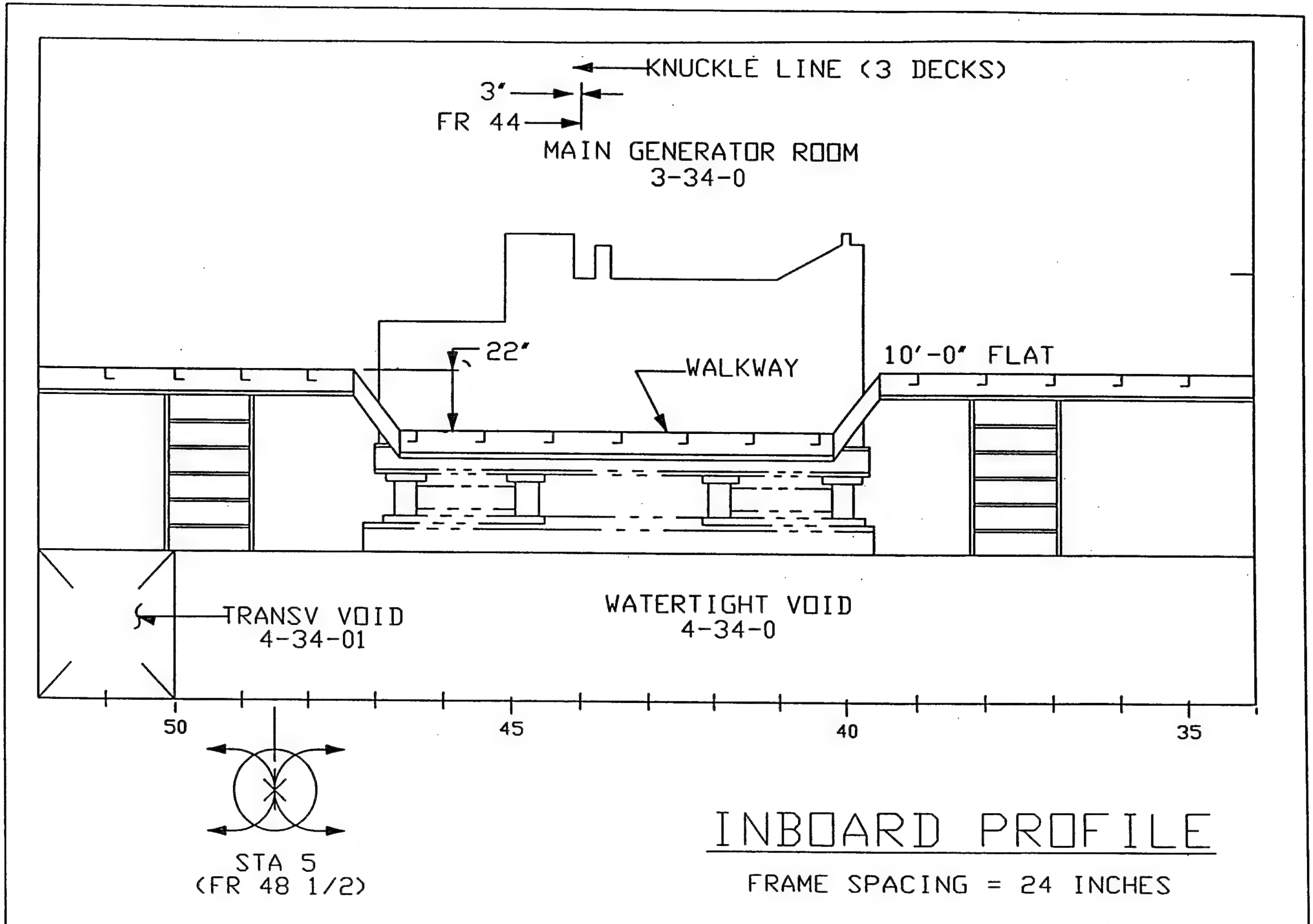
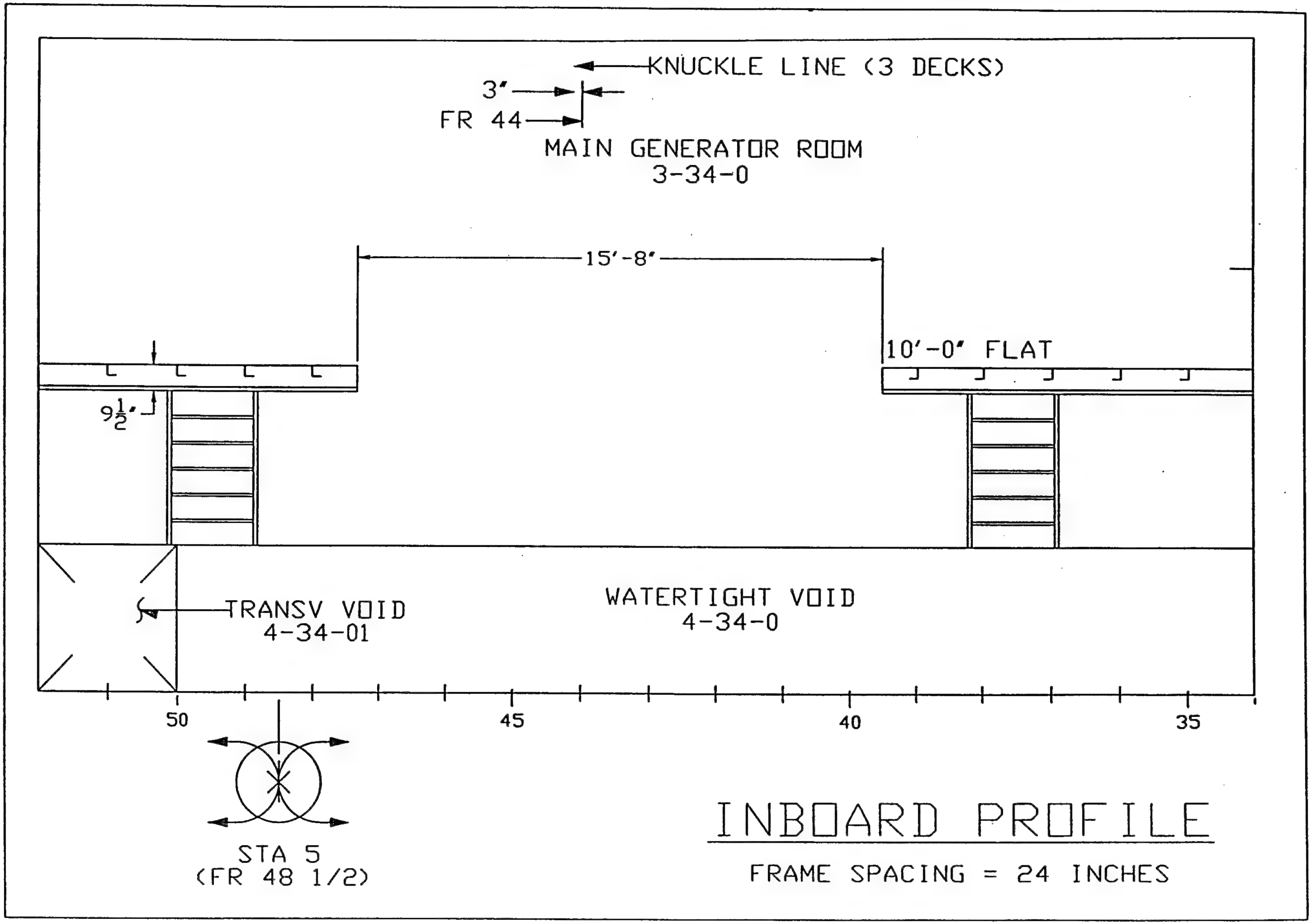


FIGURE 4-8 ELEVATION VIEW AFTER REMOVAL OF DIESEL ENGINES AND BEDPLATES



The next significant deletion of weight occurs for the Group 310 ELECTRICAL POWER GENERATION. This is the four diesel engine generators with their associated circulating water jackets and cooling water heat exchangers. The weight figure for Group 310 is 41.750 LT. The fuel cell modules are air cooled and will require some auxiliary cooling water cooling. Therefore the 41.750 LT is not fully eliminated. It is reduced by 39.663 LT, which attributes essentially 10 LT per 600 kW diesel engine generator assembly.

The next weight deletion is to the Group 314 POWER CONVERSION EQUIPMENT. This group contains the Silicon control rectifiers (SCRs) used to rectify and control the AC output from the diesel electric generators. Because fuel cells produce DC power this exact form for the power conversion function is not required. 10.924 LT of this Group 314's baseline 11,499 LT of equipment is therefore deleted.

The Code 324 SWITCHGEAR & PANELS weighs 15.501 LT. 13.951 LT of this equipment, appropriate to the no-longer-fitted diesel electric generators, is therefore removed.

The next weight deletion is most of the 11.161 LT of the Group 491 ELECTRICAL TEST CHECKOUT AND MONITORING EQUIPMENT which was originally part of the Navy SURTASS system. 10.603 LT can be removed leaving a small number of appropriate test equipment still available on board. Because modular changeout fuel cell power plants are not serviced on board there is less need for service equipment.

The summary of these weight deletions are found on sheet 7 of the Table 4-3 spread sheets FCVTREP.XLS. The weight reduction totals 127.836 LT, or close to a 9% reduction in the Light Ship condition.

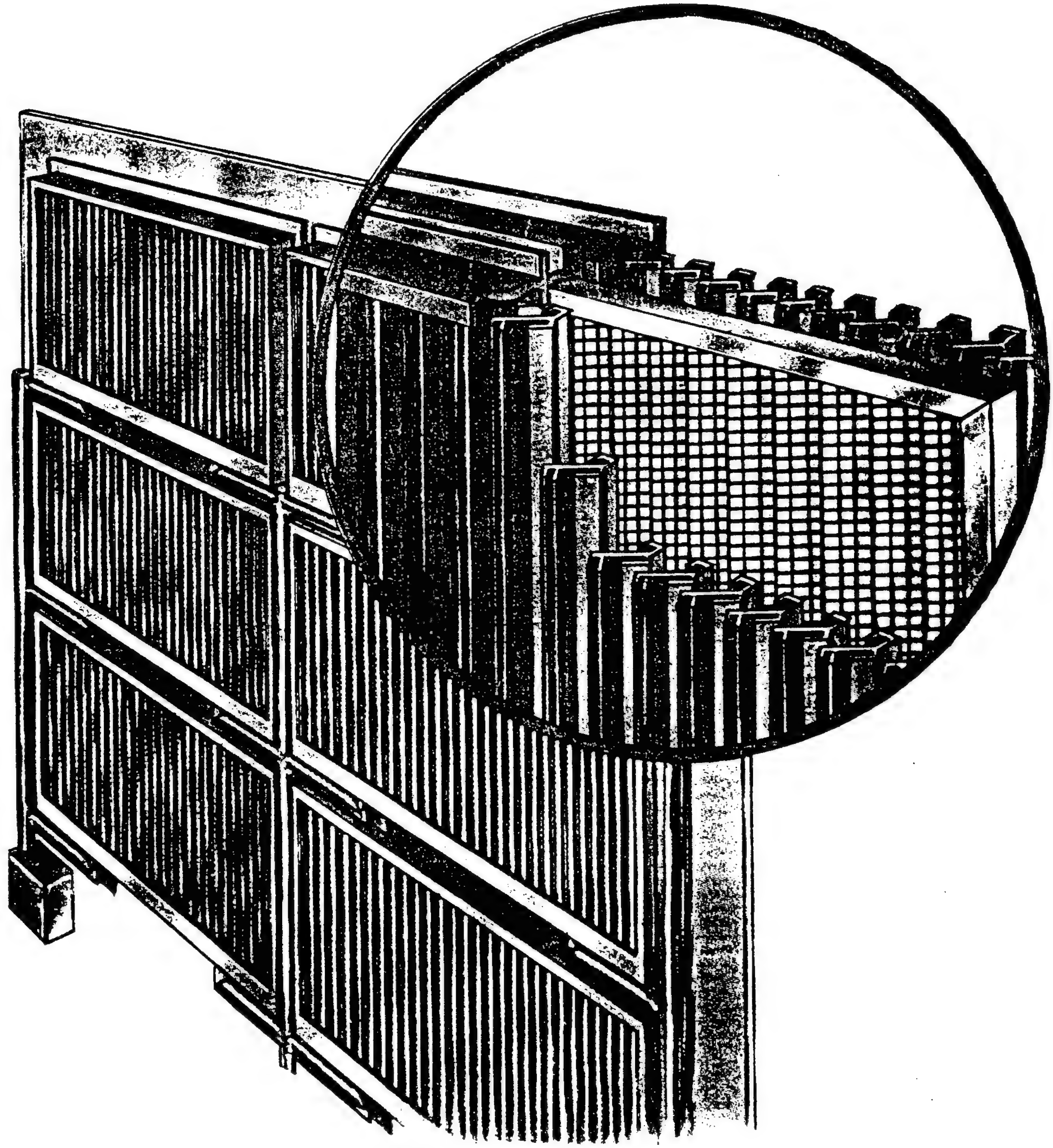
The modular fuel cell power plant electrical system will add certain Group weights to the ship. They are now described. Following this step the reductions and the additions are summarized, as shown at the bottom of sheet 7 of the Table 4-3 spread sheets FCVTREP.XLS for the fuel cell powered USCG demonstration ship VINDICATOR.

The one-sided-fit modular fuel cell power plant system weight additions start with Group 183 ELECTRICAL FOUNDATIONS under which deck and below-deck service ducts and piping are added to feed the 12 one-sided-fit 215 kW power modules. This structural weight increase is estimated at 14.964 LT.

The Group 259 UPTAKES adds an additional 0.500 LT of weight to the port intake to account for a multi stage but light weight vane/coalescer/vane type salt spray trapping system for the intake air supply, as shown by Figure 4-9.

Group 304 ELECTRICAL CABLE adds new type fuel cell modular power plant distribution electrical cabling to the extent of a 12 LT increase or on the basis of 1 LT/module.

FIGURE 4-9 VANE/COALESCER/VANE SALT SPRAY TRAPPING SYSTEM



The Group 310 ELECTRICAL POWER GENERATION adds the 12 one-sided-fit modules with an estimated weight figure per 215 kW module of 5.65 LT. 5.65 x 12 = 67.8 LT. The fuel cell module conceptual design has not as yet been subjected to any weight reduction effort. Such an effort could readily bring the module weight down to on the order of 4 LT each or 48 LT per 12 module installation. When one considers that the four diesel generators plus their sound insulating bed plates weigh on the order of 70 LT, the current conceptual design fuel cell modules will weigh less than or equal to the diesel engine generator system, to a first approximation. Weight reduction efforts applied to the fuel cell power modules will reduce their weight significantly in the next step preliminary design process. The air cooled fuel cell power system does not involve any of the diesel engine type of water jacket cooling with a closed fresh water loop and a liquid-to-liquid (seawater) heat exchange. Therefore there is an inherent fuel cell power plant associated air cooling system weight advantage. In addition, because fuel cell power plants are twice as energy conversion efficient compared to diesel engine generators there is only half as much fuel cell waste heat produced which would need to be removed from the VINDICATOR's fuel cell power plant room. A figure of 67.8 LT is used for the 12 modules.

The Group 324 SWITCHGEAR AND PANELS requires the addition of DC switchgear appropriate to the DC output fuel cell type of power plant. New custom built DC switchgear has been assigned a generous estimated weight addition of 17.862 LT. This completes the weight estimate additions to the fuel cell powered VINDICATOR.

Thus, the 127.836 LT of light ship weight reductions from the removal of the diesel engine generated electric power is then added to the modular air cooled fuel cell power system weight of 113.126 LT, based on no fuel cell power plant weight reduction effort being expended. The net decrease in the light ship weight is then -127.836 + 113.126 = -14.710 LT for the fuel cell powered ship.

4.3.3. ARRANGEMENT IMPACTS

4.3.3.1 Light Ship Arrangement Weight Impacts

The fundamental arrangement weight reduction impacts of the fuel cell powered VINDICATOR are as follows:

- Less high up weight due to the removal of both stacks on the bridge deck as well as the four high up engine exhaust silencers.
- Less weight due to the removal of the un-needed sound isolation bedplates below the four diesel engine generators.
- Less cooling system weight due to half the waste heat being produced by fuel cells and the air cooled approach.

- No requirement for the engine lubrication oil system with its equipment weight. The impact of the lubrication oil weight is covered in Section 4.3.3.2.

- Potential for substantial incremental modular fuel cell power plant weight reductions as the VINDICATOR ship configuration design is refined in preliminary design.

- Potential for meaningful DC powering conditioning and DC propulsion motor control systems weight reductions as the preliminary design is carried out in detail.

4.3.3.2. Full Load Conditions Weight Impacts

Due to the exceptional improvement that the fuel cell type of power plant offers in reducing the fuel consumption rate and increasing speed, as was detailed in Section 4.2.3., it becomes possible to cut the variable load Group 822 FUEL OIL load by 175 LT. The ship range at, say, 9,775 NM will be the same as before but using far less fuel so to do.

The elimination of the engine luboil system means a reduction in the weight of Group 819 LUBE OIL by 27.388 LT from the original weight of 34.485 LT. Some lube oil is still required for the lubrication of the bearings of the two main electric propulsion motors.

The combination of these two fuel cell arrangement weight impacts is -175 LT + (-)27.388 = -202.388 LT in the equivalent 75% of full fuel load condition.

This figure can be added to the above calculated Section 4.3.2.2. light ship arrangement weight reduction of 14.710 LT for a total weight reduction of 217.098 LT for the fuel cell powered VINDICATOR in this "ready-for-sea-duty" load condition.

The fuel cell powered VINDICATOR weight reductions are, for the most part, close to the centerline of the ship as well as close to the longitudinal center of gravity. The effect on trim is therefore negligible although the reduction of draft could be beneficial for transit speed enhancement as was discussed in Section 4.2.3 and shown in Figure 4-6.

4.4. Vessel Performance Assessment

The VINDICATOR will gain approximately 2 knots in maximum speed from the reduction in displacement. The ship will use less fuel for each nautical mile traveled at sea as well as each hour waiting at the pier.

4.4.1. RANGE

The range for the vessel at six knots and the reduced fuel tankage is approximately 28,000 nautical miles for the fuel cell configuration versus 28,600 nautical miles on twice the fuel for the baseline diesel engine generator configuration.

4.4.2. MINIMUM STEERAGE, CRUISING AND FULL POWER SPEED

The configuration of chosen for the VINDICATOR allows normal operation of the propulsion control system for speeds up to six knots. The minimum steerage power requirements have been reduced based on the reduced displacement. The changes are small and it is expected to improve steerage in a minor way. The cruising speed of 11 knots may be increased up to 14 knots based on the reduced powering required because of the reduced fuel consumption and vessel displacement. The full power speed of 12 knots has been increased to 14 knots based on reduced fuel consumption and reduced displacement. We are confident that higher power to the propulsion motors will result in increased full power speeds as needed by the United States Coast Guard. The main propulsion space is capable of accommodating up to 24 fuel cell modules, or about 4.8 megawatts of power. This means that as much as 4 megawatts of power could be used to power a longer, faster ship optimized for maximum speed. The predicted speed/power curve for the modified VINDICATOR would suggest that speeds up to 18 knots are possible.

4.4.3. ACCELERATION

The ship acceleration is expected to improve based on reduced displacement and more available propulsion power. Based on linear analysis the expected acceleration to 12 knot should improve by about 9% with about the same time being required to reach 14 knots as would the baseline ship to reach 12 knots.

4.4.4. MANEUVERING

The repowered ship maneuvering is expected to remain about the same as for the baseline ship. The change in displacement and powering will allow a marginally quicker response as more power will be available. Less shaft horsepower is needed to move the ship at the lighter displacement.

4.4.5. REDUCED FUEL REQUIREMENTS

The fuel required to match the old 10,000 nautical mile endurance figure will be about half that of the baseline ship. We have chosen to reduce the fuel load to half that in the baseline design in order to improve the ship performance and speed.

4.5. Environmental Analysis and Considerations

The environmental conditions at sea present some significant environmental issues for any system. Currently power generation systems are contained within the main engine room and protected by demisters in the intakes. This is done to protect the diesel prime mover and to help reduce airborne noise propagation. Diesel engines are good in a cold startup condition provided proper steps are taken in the sequence. The fuel cell modular design control system and air cooling system can, however, be properly sized to accommodate these cold startup conditions.

The inherent quiet operation of fuel cell power systems, the sulfur-free fuel (which eliminates the fuel smell), the air-to-air heat transfer to the man-rated spaces and the modularity at the nominal 215 kW module size, will permit the modules to be placed not only in the main engine room, but inside other man-rated spaces. No diesel electric plant sound isolation or dedicated exhaust silencer system is involved. This is a distinct advantage in the design for new vessels.

The coastal zone atmosphere has been greatly influenced by pollution sources such as ships located and operating in the coastal regions as well as from local coastal industrialization. As more pollution from outside the coastal regions has its effect, the amount and type of pollution created in the region will also become more critical. Diesel generators, desalination plants, space heaters and aviation related sources can be major contributors to local airborne pollution. Reducing coastal ship-generated atmospheric pollution should be a high priority for US Government ship operating agencies because it is coupled with pollution sources outside the area. These coastal man-made sources produce SO_2, NO_2, PM-10, VOC and CO.

For the case of the VINDICATOR the estimated diesel generator power plant created air pollution emissions per year are summarized in Table 4-4. The procedure used in making the Table 4.4 and Table 4.5 calculations was developed by AEL during work for the National Science Foundation (NSF) Office of Polar Programs (OPP) in 1991 on Antarctic applications for fuel cells in place of diesel electric generators at the South Pole [13,14].

TABLE 4-4 VINDICATOR ESTIMATED DIESEL GENERATOR AIR POLLUTION EMISSION IN TONS PER YEAR

SOURCE	SO_2	NO_2	PM-10	VOC	CO
DIESEL GEN SETS	32.8	496.2	32.8	46.6	106.9
TOTAL	32.8	496.2	32.8	46.6	106.9

The following Table 4-5 is summarized from estimated emissions at full power with added appropriate comparison data for the fuel cell modules. Table 4-5 assumes that the new total reflects complete use of fuel cell modules to supply electricity, water and heating by using the same quantity of fuel. This gross estimate is conservative because the modules will, in fact, use significantly less fuel than the present systems. The fuel cell parameters are from DFC tests run by Energy Research Corporation (ERC) on one 125 kW module of their two megawatt power plant located in Santa Clara, California. Southern California has the most demanding air quality standards in the US as is shown in the Proposed California Air Resources Board (CARB) standard in Figure 4-10.

TABLE 4-5 VINDICATOR ESTIMATED FCM POTENTIAL AIR POLLUTION EMISSION IN TONS PER YEAR

SOURCE	SO_2	NO_2	PM-10	HC	CO
DFC MODULES (ALL)	0.0004	0.0	0.0	0.0	0.0
TOTAL	0.0004	0.0	0.0	0.0	0.0

As shown in Table 4-5 the new total air pollution is so low because fuel cell power systems are environmentally benign. The SOx and NO_2 is estimated based on old data and may be as low as zero. No other impacts are estimated to occur because of the fuel cell modules. The fuel cell process does not burn fuel at steady state, it electro-chemically converts the fuel to electricity, water, and carbon dioxide. Revising the present Federal Fuel Supply System's diesel fuel specification to require sulfur free content will add the bonus of eliminating the SO_2 pollution by all other users, such as vehicles, aircraft and portable diesel fueled systems. These results, once confirmed in the planned AEL 215 kW modular DFC internal reformation fuel tests, using sulfur-free diesel fuel, will be a further substantiation of the significant benefits of fuel cells for maritime uses.

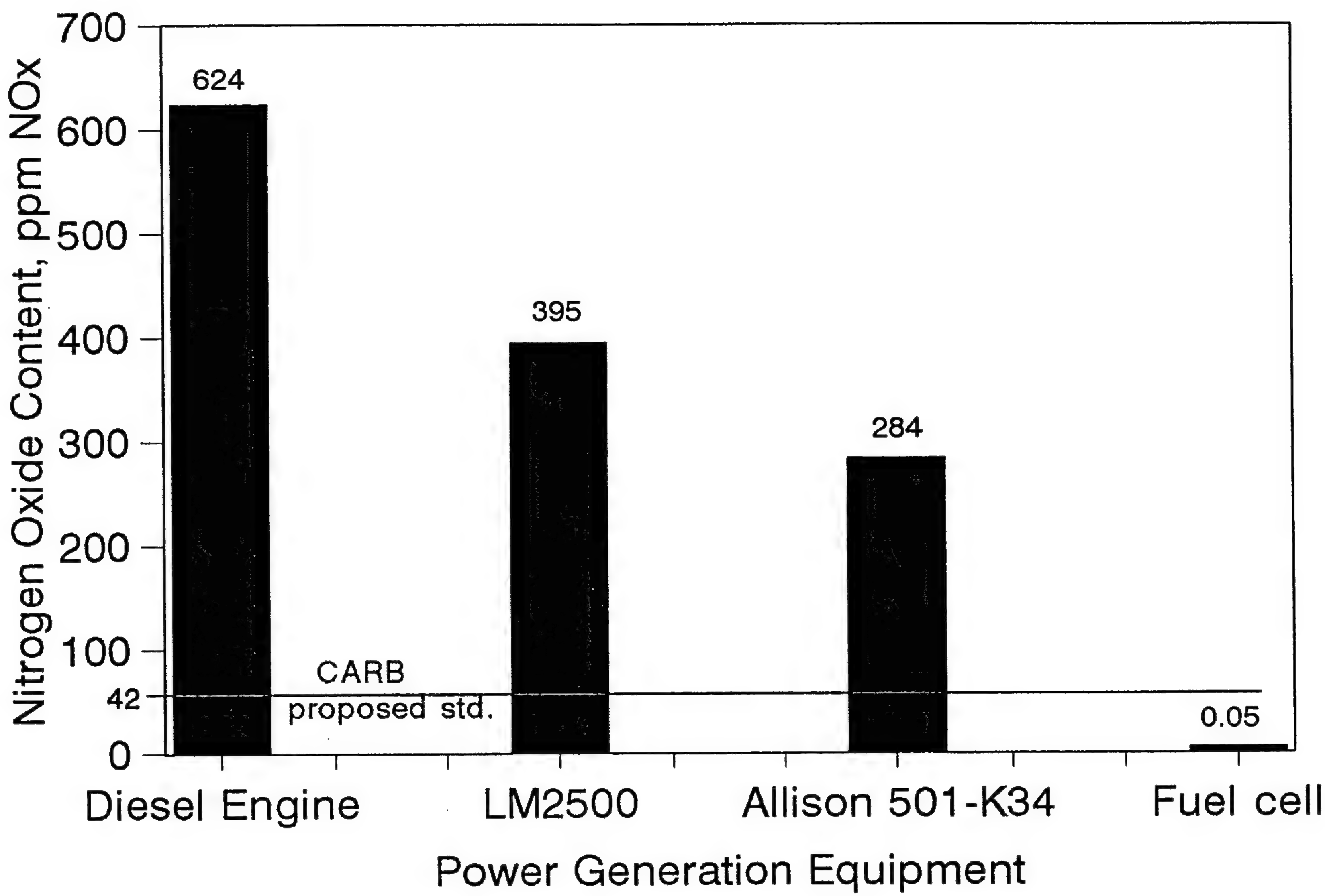
4.5.1. RECYCLING FUEL CELL MODULES

The fuel cell modules are fully recyclable. The stacks are composed of stainless steel, non-hazardous molten carbonate matrix and mild steel structural components. The balance of plant components are mild steel, insulation, stainless steel, electronic subcomponents and copper for cable connections and electrical lugs. The fuel cell modules are expected to be reworked at repair facilities that are similar to aero-turbine repair facilities. All components are expected to become commodities.

4.5.2. NOISE, VIBRATION AND ELECTROMAGNETIC RADIATION

The noise, vibration and electromagnetic radiation from the modularized fuel cell power plants are expected to be similar to those of HVAC rotating air handling motors and fans used for marine vessels. The electromagnetic radiation from the fuel cell stacks could be the subject of a research and monitoring task during the preliminary design. The operation of the ERC 2 megawatt demonstration system at Santa Clara, California has not revealed any apparent electromagnetic radiation issues in the natural gas fueled land based electric utility configuration.

FIGURE 4-10 CALIFORNIA AIR RESOURCES BOARD (CARB) STANDARD COMPARISON



4.5.3. CALIFORNIA EMISSIONS STANDARDS FOR VESSELS

The fuel cell module is expected to significantly exceed the reductions needed to meet the California Emissions Standards for Vessels. The emissions are so low that the air exiting the ship will be cleaner than the air entering the ship. The SOx production for the 2.5 megawatts is on the order of 1 pound versus the nearly 32.8 tons per year for the 2.4 megawatt diesel generator baseline system. The production NOx is cut almost 500 tons per years using the 2.5 megawatts of fuel cell modules.

4.5.4. SHIPBUILDING MACT STANDARD IMPACT FROM FUEL CELLS

The US EPA shipbuilding MACT was reviewed to ensure no impact would occur because of the use of fuel cell modules. The MACT does not impact the shipbuilding industry significantly in the case of a conventional or fuel cell repowering.

4.6. Central Control System Notional Design

The central control system notional design is to retain the functional ship system for speed up to 6 knots and add the capability to schedule VDC to the propulsion motors up to speeds of 14 knots using custom switchgear for directly connecting approximately 1.8 to 2.0 megawatts. Commercial control system design will be the subject of a preliminary design study task.

4.7. Special Operating Considerations

The repowered ship is expected to operate much as the baseline design ship does with no special operating considerations based on the compatibility of the fuel cell modules to the existing ship design.

4.8. Dynamic Analysis

The preliminary design will include a computer based dynamic analysis to confirm that the power system will experience smooth operation for all speeds and electric loads. Greater design detail on each of the systems is necessary to reasonable predict the dynamic response of the fuel cell modules, control system and switchgear to the operation of the ship.

4.9. Acoustic Analysis

Fuel cell modules can be located much closer to manned spaces than present engine generator power systems simply because they are environmentally benign to the local environment and operate below fifty-five (55) dBm noise level at 100 feet. Special acoustic treatment of the air handling blower system for the fuel cell modules could reduce this noise level even more.

4.10. Special Structural Analysis of the Module

The structural analysis of the module is focused on the critical components such as the lifting

rods during installation and removal. Dynamic loads such as those caused by ship motion, once installed in the ship, are expected to be less that those experienced during installation and removal. The mild steel 3/4 inch rods are expected to yield under loads of 40,000 PSI or greater.

4.10.1. SPECIAL STRUCTURAL ANALYSIS ONE G LOADING CRITERIA

The expected static loads are found by the product of the fuel cell module weight of 14,900 pounds / 4 rods x 0.75 x 0.75 x 3.1416 = 2,107 PSI or a factor of safety of almost 19 time the load to yield the rod.

4.10.2. ONE G LOADING CRITERIA ANALYSIS

The one G loading Criteria Analysis process was not provided for this report.

4.10.3. HIGHER LOADING ANALYSIS

During the preliminary design MSC NASTRAN structural analysis of the details of the fuel cell module should be the subject of a design task. Criteria similar to MIL-C-901 should be used to evaluate the structural integrity of the fuel cell module.

4.10.4. ROLL ANALYSIS

The fuel cell modules are expected to withstand the athwartship roll components up to 90 degrees where loads will double on two of the four rods that are in tension, with two rods in compression. Internal loads should be checked using MSC NASTRAN during the preliminary design.

4.11. Manning, Training and Special Support

The yearly maintenance on the diesel generator will continue to be approximately twice the maintenance of fuel cell modules on a megawatt basis. Therefore 2.4 megawatts of diesel generators will require at least two engineer/maintenance technicians per year. The fuel cell module maintenance could readily be accomplished by one person. This implies that the reduction in maintenance will allow the USCG to reduce the crew by at least one person-year or $1,000,000.00 in cost. This personnel cost reduction figure is per year and before any fuel efficiency cost reductions are counted.

4.12. Maintainability, Availability and Evaluation

The present electric utility type DFCs undergoing accelerated testing have demonstrated full power MTBF values of at least 40,000 hours. Because the DFC stacks in the VINDICATOR modules will be from the newest (9 ft^2) design concept, it is estimated that the stack life could grow to 58,000 hours MTBF based on the limits of the present internal stack gasket design and material used. In other words, the individual cell lives are not life-limiting, the present

stack gaskets appear to be the limiting factor.

The AEL engineering experience indicates that the one-sided-fit modular system is necessary to efficiently package the DFC stacks to keep the unit cost low, reduce installation cost and ensure ease of replacement at the single stack level. In addition, the ultimate user is assured of better integration, superior energy conversion efficiency and ease of use by having the modular design. Location, orientation and sizing can be readily planned, making engineering of the power plant spaces easier. Periodic scheduled replacement with upgraded technology modules (over the ship life of 30 or more years) is significantly enhanced because the modular one-sided-fit interfaces remain the same.

Fuel cell modules can be held in warm standby or cold shutdown. Extended warm standby can be accomplished by dehydrating the cooling gas stream as the temperature is reduced. Carbon dioxide or nitrogen from the cathode exhaust stream can be used for a blanket for short duration shutdowns. For longer periods of time sealing the system with dry nitrogen is all that is necessary.

4.13. Evaluation and Reduction of Risk

The present ERC 12 ft tall, 6 ft^2 cell DFC stacks for the electric utility market have been produced in stack sizes of 125 kW and are expected to hold little technical risk because of the simple stack design. The second generation 9 ft^2 cell DFCs, (to be built to the AEL designated 6 ft height), are already undergoing cell life tests at ERC in short i.e. ten to twenty cell stacks. The stack associated balance of plant components in the marine fuel cell module need full scale development and testing at a land based site prior to introduction into the VINDICATOR. This feasibility study has started the detailed engineering process of fully defining the marine service fuel cell module "from the stack out to the ship". The creation of the highly precise drawings, models and computer analyses during the preliminary design phase is necessary to reduce the program's technical risk. Funding resources to conduct the engineering design, the analyses and tests of the first 215 kW fuel cell module is where the risk is currently most apparent in this program. The technical process is well known and the needed expertise is available and well defined.

4.14. Ship Construction and Backfit Assessment

The introduction of a "false floor" or deck in the VINDICATOR's "engine room" with service ducts below, with appropriate thermal insulation for standoff, will allow the installation of DFC modules using existing facilities. By providing clear space on all sides each of the "one-sided" (bottom) fit modules personnel can access all sides of the modules for inspection, cleaning and routine maintenance.

AEL is confident that the repowering with the 215 kW fuel cell power plant modules can be accomplished in a efficient and speedy manner. The modifications to the ship can be accomplished in a routine shipyard overhaul/repowering environment.

5. FUEL CELL SPECIFICATION IMPACTS

The development of a more detailed fuel cell module specification is the most important needed effort during the preliminary design. The particular care taken by AEL to prepare a "solid model" of the fuel cell power plant module during this feasibility study means that the preliminary design process will start from a technically accurate and internally consistent module design configuration. To reiterate, in the mechanical engineering sense, the AEL prepared solid model of the module has no physical interferences between components, in all three axes i.e. X, Y or Z.

The needed detailed engineering design and analyses and subcontractor input will allow the proper interfacing of all fuel cell subsystems that support the full scale development of the fuel cell module. The following section discusses the steps needed in this process and describes the known technical issues.

5.1. Approach

The approach used to develop the specification will include four major activities. They are:

1. The development of a preliminary design drawing hierarchy or "tree", using the USCG drawing standards, for the VINDICATOR, to more fully document the desired ship configuration in 3D. This will be done using more detailed 2D ship design drawings as the starting point, detailed checking of drawing dimensions and equipment locations by physical inspections and measurements on board, plus accessing other sources of information. It is worth recalling that all of the USCG shipbuilder's drawings provided to AEL in the "scanned into AUTOCAD form" are dimensionally and orthogonally inaccurate, as was pointed out in Section 4.3.2.2 titled "Diesel Engined to Fuel Cell Powered Changes".

2. The preparation of a ship specification including the details of the physical configuration in preliminary design documents such as equipment lists, interface detailed drawings, the needed control system specification with the changes from the current control system clearly set out, the electrical system dynamic analysis, and a more detailed weight runs.

3. A full scale fuel cell module mockup, with detailed structural analyses (including computer models and simulations).

4. A full scale module incorporating a 215 kW stack and all the associated "balance of plant" and test equipment hardware needed for power cycling and life "bench tests", including a detailed test program plan.

5.2. Specification Preparation Considerations

The Preliminary Design Report development process will yield a detailed specification for the ship and the 12 fuel cell modules. Drawings, material lists, detailed structural analyses and other design documentation will be developed to support the pier-side land based modularized fuel cell power plant testing. It will also provide the detailed ship and hardware design for the VINDICATOR. The Preliminary Design Report will serve as the "bid package" for the shipyard which will then complete the detailed ship design and construction process of repowering the VINDICATOR.

5.3. Drawing Preparation Considerations

USCG management needs to permit the latest computer technology and the most up-to-date software to be used in the VINDICATOR fuel cell powering project. Unfortunately, this was not automatically done in the first stage feasibility study and it negatively impacted productivity.

5.4. Stack Supplier Fuel Cell Performance Evaluation Criteria

The fuel cell stack supplier (ERC) has had substantial recent laboratory and field test experience in stack hardware performance evaluation for land-based electric utility applications. For the marine applications it is important to define the test methods and criteria to be used to determine the functioning of stacks produced for the VINDICATOR and subsequent ships. The long term performance criteria will be based on the results of the preliminary design process followed by the results from the fuel cell module operation at the factory test facility.

5.5 Fuel Cell Module Hardware Specification

Appendix A contains the feasibility study level description and fifty drawings on the fuel cell module assembly as defined to date. During the preliminary design study the process of revision of the Fuel Cell Module Hardware Specification will focus on refining fuel cell module design into a full commercial specification. It will contain a complete list of equipments and needed performance parameters. Detailed drawings of all components and interface drawings will be produced in order to support procurement of a containerized demonstration fuel cell module to be used for on-land testing and later at-sea tests as a deck mounted container.

The containerized demonstration unit will house both a fuel cell module as well as all of the necessary balance of plant plus performance measuring and data logging equipment. It may include a 215 kW dummy resistive load to absorb the power produced. Alternatively, it could serve as the provider of a part of the "shore power" for the VINDICATOR at the pier in which case the load would be both resistive and reactive. The load aspect will need to be negotiated in the Containerized Power Module Design second stage of the VINDICATOR fuel cell powering project.

6. COST ANALYSIS

6.1. Methodology

AEL has determined that because of the relative lack of information available on the current USCG VINDICATOR notional operation a conceptual speed and electric load profile was used in the two step economic analysis.

First, a basic construction cost estimate was prepared for a notional 2.5 megawatt fuel cell ship power plant. Then this was contrasted to the present 2.4 megawatt diesel generator powered or "baseline" system. From information about the hardware elements an estimate for operations and maintenance was made for a system equal to the total installed power for both the baseline and the fuel cell systems. To this was added to the total cost of fuel using both systems. This procedure permits a parametric analysis of the life cycle cost of the present baseline system and modularized DFC system to be carried out.

6.2. Systems Cost Description

The estimated DFC module system costs are based on an average of $1,900 per installed kilowatt, which includes all the auxiliaries. The Section 2.2.20 MODULE COST PARAMETERS mentions an electric utility sector mass production cost target of $1,000/kW. For the initial quantities of the 215 kW modularized marine application diesel fueled DFCs, including the balance of plant (BOP), at the pilot mass production level of 12 modules, the figure of $1,900/kW is used. The pilot mass production of twelve 215 kW modules would commence in 1999. The cost is for DFC module system and does not include the associated distribution system and special systems. The estimated acquisition and installation costs for the present diesel generator system and the DFC module system are contained in TABLE 6-1 and TABLE 6-2 respectively. The system cost analysis for the DFC modules is based on detailed design information contained in Appendix A. The estimated installation cost for the new diesel generator is derived using US Navy factors for acquisition cost, which is typical for marine applications.

6.2.1. ACQUISITION COST ANALYSIS

The acquisition cost analysis compares the baseline of the first ship as if built in 1997 and the fuel cell repowered ship as if built in 1997. This yields a "delta" for the cost, as shown in TABLE 6-2, in the SHIP COST column, that supports future fuel cell module ship acquisitions in a context that relate directly to new construction. Repowering estimates are a function of the specific shipyards competing and the method of government/contractor procurement split of hardware acquisition. The delta cost figure of $ 3,039,043.15 generated in this study provides a starting point for estimating program costs. The preliminary design phase will develop the necessary work package detail to allow accurate cost estimates to be made by the appropriate shipyard.

TABLE 6-1 ESTIMATED FUEL CELL MODULE (FCM) TOTAL CONSTRUCTION AND INSTALLATION COST

BASIC CONSTRUCTION COST MODEL

FCM Baseline 97

PRODUCTION COST	$14.35 HOURLY	OVERHEAD	%	1.18
ENGINEERING COST	$15.55 HOURLY	PROFIT	%	0.10

SWBS	WEIGHT	MATERIAL	LABOR	TOTAL
100	778.31	$946,420.10	78608.91	$3,399,902.31
200	23.48	$927,390.64	5941.20	$1,112,822.88
235	79.82	$4,902,087.73	841.42	$4,928,349.66
300	69.27	$2,627,442.44	74464.18	$4,951,562.42
400	9.49	$375,728.08	3416.40	$482,358.19
500	213.98	$2,431,454.74	72325.24	$4,688,815.89
600	161.93	$2,175,624.30	29308.43	$3,090,376.88
700	0.12	$272.57	21.40	$940.55
	103.38			
SUB-TOTAL	1439.77	$14,386,420.59	264927.17	$22,655,128.79
800		$246,201.09	115181.79	$4,141,793.35
900		$719,886.21	67669.30	$3,008,546.67
SUB-TOTAL		$966,087.30	182851.10	$7,150,340.01
TOTAL	1439.77	$15,352,507.89	447778.27	$29,805,468.80
PROFIT	10 PERCENT			$2,980,546.88
TOTAL BASELINE	1439.77	$15,352,507.89	447778.27	$32,786,015.68

NON-RECURRING COSTS

810			50	575.91	$19,477.96
830	90	$209,615.60	90	90187.34	$3,259,864.34
850	90	$11,965.37	90	6738.13	$239,857.52
TOTAL NON-RECURRING COSTS		$221,580.98		97501.39	$3,519,199.82

MULTI SHIP CONSTRUCTION COST MODEL

	MATERIAL LEARNING FACTOR	LABOR LEARNING FACTOR	SHIP COST
FIRST SHIP	1.000	1.000	$32,786,015.68
SECOND SHIP	0.920	0.920	$27,421,031.30
THIRD SHIP	0.880	0.880	$26,228,812.54
FOURTH SHIP	0.850	0.850	$25,334,648.48
FIFTH SHIP	0.820	0.820	$24,440,484.42
SIXTH SHIP	0.800	0.800	$23,844,375.04
SEVENTH SHIP	0.800	0.800	$23,844,375.04
EIGHTH SHIP	0.800	0.800	$23,844,375.04
NINTH SHIP	0.800	0.800	$23,844,375.04
TENTH SHIP	0.800	0.800	$23,844,375.04
CLASS TOTAL			$255,432,867.62
CLASS AVERAGE COST			$25,543,286.76

TABLE 6-2 ESTIMATED TOTAL BASELINE CONSTRUCTION AND INSTALLATION COST

BASIC CONSTRUCTION COST MODEL

SHIP Baseline 97

PRODUCTION COST	$14.35 HOURLY	OVERHEAD	%	1.18
ENGINEERING COST	$15.55 HOURLY	PROFIT	%	0.10

SWBS	WEIGHT		MATERIAL		LABOR	TOTAL
100	807.43		$981,834.88		81550.43	$3,527,125.74
200	70.99		$2,803,655.56		17961.23	$3,364,247.96
300	97.23		$3,687,917.34		104519.03	$6,950,086.76
400	35.28		$1,396,647.39		12699.36	$1,793,010.29
500	269.77		$3,065,385.15		91181.92	$5,911,286.91
600	155.55		$2,089,969.80		28154.55	$2,968,708.50
700	0.12		$272.57		21.40	$940.55
	185.13					
SUB-TOTAL	1621.50		$14,025,682.68		336087.92	$24,515,406.71
800			$277,275.65		129719.60	$4,664,554.67
900			$810,747.50		76210.27	$3,388,273.93
SUB-TOTAL			$1,088,023.15		205929.87	$8,052,828.59
TOTAL	1621.50		$15,113,705.83		542017.78	$32,568,235.30
PROFIT	10 PERCENT					$3,256,823.53
TOTAL BASELINE	1621.50		$15,113,705.83		542017.78	$35,825,058.83
NON-RECURRING COSTS						
810				50	648.60	$21,936.40
830		90	$236,072.48	90	101570.45	$3,671,311.96
850		90	$13,475.60	90	7588.60	$270,131.42
TOTAL NON-RECURRING COSTS			$249,548.08		109807.64	$3,963,379.77

MULTI SHIP CONSTRUCTION COST MODEL

	MATERIAL LEARNING FACTOR	LABOR LEARNING FACTOR	SHIP COST
			$3,039,043.15 DELTA
FIRST SHIP	1.000	1.000	$35,825,058.83
SECOND SHIP	0.920	0.920	$29,962,776.48
THIRD SHIP	0.880	0.880	$28,660,047.07
FOURTH SHIP	0.850	0.850	$27,683,000.01
FIFTH SHIP	0.820	0.820	$26,705,952.95
SIXTH SHIP	0.800	0.800	$26,054,588.24
SEVENTH SHIP	0.800	0.800	$26,054,588.24
EIGHTH SHIP	0.800	0.800	$26,054,588.24
NINTH SHIP	0.800	0.800	$26,054,588.24
TENTH SHIP	0.800	0.800	$26,054,588.24
CLASS TOTAL			$279,109,776.54
CLASS AVERAGE COST			$27,910,977.65

6.2.2. REMOVAL COST ANALYSIS (10 SHIPS)

The removals are included in the parametric models so that an examination of that cost is available for planning and budgeting purposes. The removals for the repowering cost

approximately $1,535,006.59 for all items identified as required in the modified weight report. Salvage of the removed materials may reduce the cost, but is difficult to estimate. The cost is significant and reflects the inevitable capital cost aspect of repowering a ship, or 10 ships of a class in this case.

TABLE 6-3 ESTIMATED REMOVAL COST

BASIC CONSTRUCTION COST MODEL

FCM Baseline Removal 97

PRODUCTION COST	$14.35 HOURLY	OVERHEAD	%	1.18
ENGINEERING COST	$15.55 HOURLY	PROFIT	%	0.10

SWBS	WEIGHT		MATERIAL		LABOR	TOTAL
100	5.90		$717.80		59.62	$2,578.63
200	48.18		$190,276.41		1218.98	$228,322.27
235	0.00		$0.00		0.00	$0.00
300	73.90		$280,306.30		7944.14	$528,252.91
400	0.00		$0.00		0.00	$0.00
500	0.00		$0.00		0.00	$0.00
600	0.00		$0.00		0.00	$0.00
700	0.12		$27.26		2.14	$94.06
	0.00					
SUB-TOTAL	128.11		$471,327.76		9224.88	$759,247.87
800			$21,906.13		10248.48	$368,522.53
900			$64,053.00		6020.98	$267,690.14
SUB-TOTAL			$85,959.13		16269.46	$636,212.67
TOTAL	128.11		$557,286.89		25494.34	$1,395,460.54
PROFIT	10 PERCENT					$139,546.05
TOTAL BASELINE	128.11		$557,286.89		25494.34	$1,535,006.59
NON-RECURRING COSTS						
810				50	51.24	$1,733.08
830		90	$18,650.88	90	8024.56	$290,051.52
850		90	$1,064.64	90	599.54	$21,341.70
TOTAL NON-RECURRING COSTS			$19,715.51		8675.34	$313,126.30

MULTI SHIP CONSTRUCTION COST MODEL

	MATERIAL LEARNING FACTOR	LABOR LEARNING FACTOR	SHIP COST
FIRST SHIP	1.000	1.000	$1,535,006.59
SECOND SHIP	0.920	0.920	$1,283,823.70
THIRD SHIP	0.880	0.880	$1,228,005.27
FOURTH SHIP	0.850	0.850	$1,186,141.46
FIFTH SHIP	0.820	0.820	$1,144,277.64
SIXTH SHIP	0.800	0.800	$1,116,368.43
SEVENTH SHIP	0.800	0.800	$1,116,368.43
EIGHTH SHIP	0.800	0.800	$1,116,368.43
NINTH SHIP	0.800	0.800	$1,116,368.43
TENTH SHIP	0.800	0.800	$1,116,368.43
CLASS TOTAL			$11,959,096.82
CLASS AVERAGE COST			$1,195,909.68

6.2.3. INSTALLATION COST ANALYSIS

The estimated installation cost analysis is based on a parametric model which predicts labor hours and material cost for a system installation similar to the FCM module and diesel generator sets. These estimates include time, material, estimated engineering and construction support costs. The acquisition and installation cost difference is substantial. Other life cycle costs of the electric power generation system such as operation and maintenance, are greater factors in the total cost.

6.2.4. REMOVED HARDWARE SALVAGE COST ANALYSIS

The removed diesel generator sets have substantial hardware salvage cost reduction in the case of a ship repowering. Each diesel generator set is worth approximately one half the value of a new 600 kW diesel generator set. The price for a 600 kW diesel generator set from for the type available. The VINDICATOR has four, for a total hardware approximate salvage savings of $ 200,000.00 in 1996 dollars.

6.3. Design and Construction Cost Analysis

The design and construction cost are found in ship work breakdown structure (SWBS) or weight group numbers 800 and 900 for each of the parametric cost models. The fuel cell module repowering non-recurring cost is $ 313,126.30 for the first ship.

6.4. Annual Fuel Cost for Operating Scenario

The notional operating scenario was used to compare fuel usage over twenty year period and for a class of ten ships. Fuel escalation cost expressed as a compounding of 1 %/year was used.

6.4.1. FUEL COST ESCALATION PROJECTION

The projected fuel cost accounts for the resultant inflation that has the effect of raising fuel cost over the long term. Inflation was taken to be 1% compounded yearly. Fuel costs in the past have varied based on supply and organized effort by oil producing countries to raise prices to reflect production cost and increased expectations. The starting price for regular diesel fuel was selected as $ 1.05 in 1997 dollars. The starting price for sulfur free diesel fuel was selected as $ 1.10 in 1997 dollars.

6.5. Economic Comparison Between Baseline and Repowered Ship Configurations

The Economic Comparison Between Baseline and Repowered Ship Configurations is the sum total of all cost to acquire, maintain and operate the entire notional ten ship class. The following sections discuss the results of each aspect of the economic comparison. The fuel cell repowered VINDICATOR Class will have about $ 200,000,000 less life cycle cost.

6.5.1. ACQUISITION COST OF SYSTEMS

The acquisition cost of the Fuel Cell Module and supporting equipment has been developed for the electric utility industry and cost objectives formulated. The acquisition cost estimates used in this report reflect the best information available and adjusted for the expected time frame of repowering the USCG VINDICATOR. The material and labor cost have been estimated to be approximately \$ 4,928,349.66, which reflects \$ 4,902,087.73 for the fuel cell modules and the balance for labor to install the modules.

6.5.2. INSTALLATION COST OF SYSTEMS

The estimated installation cost analysis is based on a parametric model which predicts labor hours and material cost for a system installation similar to the DFC module and diesel generator sets. These estimates include time, material, estimated engineering and construction support costs. The acquisition and installation cost difference is substantial \$3,039,043.15 for new ships. The diesel generators are cheaper on first cost, but the impact shipwide reduces the cost for fuel cell acquisition and installation. Other life cycle costs of the electric power generation system such as operation and maintenance, are greater factors in the total cost.

6.5.3. FUEL COSTS

The current estimate is derived from the fuel usage of each power system alternative and the cost of fuel which is expressed in two components. These components are fuel cost/economy, first cost allocation, maintenance and 1% escalation cost allocated by year.

A <u>DIESEL ENGINE GENERATORS</u>

The calculations are as follows:

(77.3 gallons per hour X 1.05)/975 kW	= 0.0832
300 dollars per kW/20,000h MTBF	= 0.0150
Total	=\$0.0982
One MW year	=\$860,636.31
2.4 MW year	=\$2,065,527.14

The yearly maintenance is approximately 568 manhours (from Table 4-1) and using a cost factor of \$30 dollars per hour for maintenance personnel the cost is then \$ 17,040.00. The maintenance materials cost will vary. To account for this materials cost it is generally accepted procedure to take the cost as being equal to personnel direct cost or \$17,040.00. The total maintenance estimate thus would be \$34,080.00 and one MW adjusted price would be \$34,953.85 and 2.4 megawatts \$83,889.24. The support cost to have the one maintenance person is approximately \$100,000.00 indirect. Factored this 568/2080 X 100,000.00 = \$27,307.69 and for 2.4 megawatts is \$65,538.46. The estimated total

maintenance cost for 2.4 megawatts is $149,427.70 per year.

The estimated cost for one MW year is the sum of operations and maintenance. This is $2,065,527.14 + $149,427.70 = $2,214,954.84 or $0.105353 per kWh or $105.353 MWh produced.

B DIRECT FUEL CELL MODULES

The calculations are as follows:

(46.5 gallons per hour X 1.10)/1,000 kW	= 0.05115
1,750 + 150 dollars per kW/40,000h MTBF	= 0.04750
Total	=$0.09865
One MW year	=$864,174.00
2.4 MW year	=$2,074,017.60

The yearly maintenance is approximately 260 manhours and using a cost factor of $30 dollars per hour for maintenance personnel the cost is then $ 7,800.00. As above, the maintenance materials cost will vary. To account for this materials cost it is equal to personnel direct cost or $7,800.00. The total DFC maintenance estimate would be $15,600.00. The support cost to have the one maintenance person on board is approximately $100,000.00 indirect. Factored this 260/2080 X 100,000.00 = $12,500.00. The estimated total DFC module maintenance cost for 2.4 megawatts is $33,744.00 per year.

The estimated cost for one MW year is the sum of operations and maintenance. This is $2,074,017.60 + $33,744.00 = $2,107,761.60 or $0.100255 per kWh or $100.255 per MWh produced. The first cost of fuel cells will fall to less than $1,000 per kW and this cost per kW produced will fall by greater than 50% in real dollars.

6.6. Life Cycle Cost Analysis

The life cycle cost analysis uses the above allocated cost of operation to allow comparison based on kWh produced for each of the systems. The long term effect is that for each system it becomes clear that ship installation attributes directly effect the estimated long term cost of operation and maintenance.

6.6.1. ACQUISITION COST

The acquisition cost analysis shows that the baseline ship if built in 1997 would cost significantly more. The "delta" cost supports future fuel cell module ship acquisitions for new construction. Repowering estimates are a function of the specific yards competing and the method of government/contractor procurement split of hardware acquisition. The delta cost

of $ 3,039,043.15 generated in this study is a starting point for estimating program costs. The first cost for a new ship class would be approximately $23,676,908.90 based on the cost models for the baseline and fuel cell module repowered ship.

6.6.2. FUEL COST, MAINTENANCE AND ALLOCATED FIRST COST

The operating scenario in Table 3-1 (SPEED AND LOAD VERSUS TIME) has estimated loads for propulsion and ship service. The fuel cell module powered ship has reduced propulsion loads because of the reduced displacement. The baseline diesel plant will require approximately 4,606 MWh each year to match the proposed operating profile and the fuel cell module repowered ship will require approximately 3,544 MWh per year. The ship service loads will be approximately equal at about 2,387 MWh per year.

The baseline ship will need a total of approximately 6,993 MWh per year and the fuel cell module ship 5,931 MWh per year. Using the allocated factors for fuel, maintenance and first cost, the baseline ship will cost $736,733.53 to operate for one year and $14,734,670.58 for twenty years (unadjusted for inflation) and $17,979,098.28 after escalation of 1%. This is $179,790,982.80 for a class of ten baseline ships. The fuel cell module ship will cost $594,434.48 to operate for one year and $11,8888,689.50 for twenty years (unadjusted for inflation) and $14,506,460.52 after escalation of 1%. This is $145,064,605.20 for a class of ten fuel cell module ships.

6.6.3. COMBINED SAVINGS

The combined savings calculated above is approximately the cost of one additional ship or about $34,726,377.63. The savings will grow by as much as 50% as the first cost of the fuel cell modules continue to fall with full mass production and could approach $50,000,000.00.

Again, the first cost for a new ship class would be approximately $23,676,908.90 based on the cost models for the baseline and fuel cell module repowered ship using the simple feasibility level rough order of magnitude (ROM) models. The difference of the first cost and fully allocated cost above is approximately the real fuel savings in dollars, and with the chosen cost per gallon, the number of gallons. This delta is $11,049,468.73 per year. This equals about $2,209,893,745.00 for the class.

7. SUMMARY

7.1. Results

The results of the feasibility analyses provided in Sections 1 through 6 strongly support the need to further evaluate the use of DFC module system in USCG ships. The DFC module systems is simple, environmentally friendly and extremely fuel efficient. While the first cost is currently more than conventional systems, the return in fuel savings would rapidly pay off the difference in acquisition cost between diesel engine generators and fuel cell modules. Manning could be reduced based on the extremely low maintenance required by DFC systems. Fuel cell power plants are totally silent. Products such as pure water and waste heat for space heating are available. The environmental impact is greatly reduced with DFC systems. The introduction of PM-10, CO, SO_2 and NO_2 atmospheric pollutants is vanishingly small compared with that produced by conventional Carnot cycle fuel burning devices. The summary Table 7-1 below compares the present diesel electric fuel burning system and DFC module approach. Clearly these engineering research results are consistently supportive of DFC modules for use in all the USCG fleet of ships.

The findings of the feasibility study are shown at various levels of the evaluation, from the electrical block diagram level as shown in Figure 7-1, the fuel cell powered Nominal Vindicator Electrical System, to findings in the ship weight categories, to summary findings at the ship configuration level.

In Figure 7-1 two sets of 5 of the 215 kW fuel cell modules are shown in electrical series at 810 VDC and 1.075 MW. Then the two sets of 5 modules are electrically parallel connected to produce 810 VDC at 2.15 MW for the ship's electric propulsion power need. The ship service power requirement is shown being provided through a DC to AC inverter from the remaining 2 fuel cell modules of the 12 modules in the former "engine room".

Figure 7-2 shows the equipment weight reduction in the lightship condition from the baseline diesel engine generator equipped ship to the fuel cell repowered configuration. The net weight reduction was found to be 14.7 long tons (LT).

Figure 7-3 shows the Advantages of the Lightship Weight Reductions. Two are equipment reductions and two are cooling and/or lubrication related which involve both equipment and fluids i.e. cooling water and lube oil. The reduced lube oil requirement shows up in the full load condition numbers.

Figure 7-4 shows the Full Load Weight Reductions. The lube oil requirement for the diesel engine generators having been eliminated, this reduces the lube oil need by 7.1 LT. The dramatic reduction in the fuel required is compared at a nominal operating range of 10,000 nautical miles (NM). It amounts to 175 LT. Because the ship will require much less fuel it will draw less water, by an estimated 2 ft. This will increase the transit speed by an estimated 2 knots.

TABLE 7-1 SUMMARY OF RESULTS

CRITERIA	DIESEL GENERATORS	DFC MODULES
PERFORMANCE AND REQUIREMENTS	BASELINE AND SAME	IMPROVED AND INCREASED
MECHANICAL	BASELINE AND CONVENTIONAL	SIMPLER AND MORE BENIGN
MAINTENANCE HOURS PER YEAR	568	260
$/kW INSTALLED	$ 360.00 *	$ 1,900.00 **
TOTAL COST	$179,790,982.80	$145,064,605.20
NEAR TERM $/kWh	0.105353	0.100225
ONBOARD AND OVERBOARD ENVIRONMENTAL IMPACTS	NOISY BASELINE WOULD CONTINUE CURRENT SIGNIFICANT SHIP AIR POLLUTION, ~500 TONS TOTAL PER YEAR	NEAR SILENCE, BENIGN AMOUNT OF AIR POLLUTION, ONLY 0.04 TONS TOTAL PER YEAR

NOTES:

* Mature, mass produced technology.

** Young, pilot production advanced technology. Capital cost will continue to decline as mass production accelerates.

FIGURE 7-1 NOMINAL VINDICATOR ELECTRICAL SYSTEM

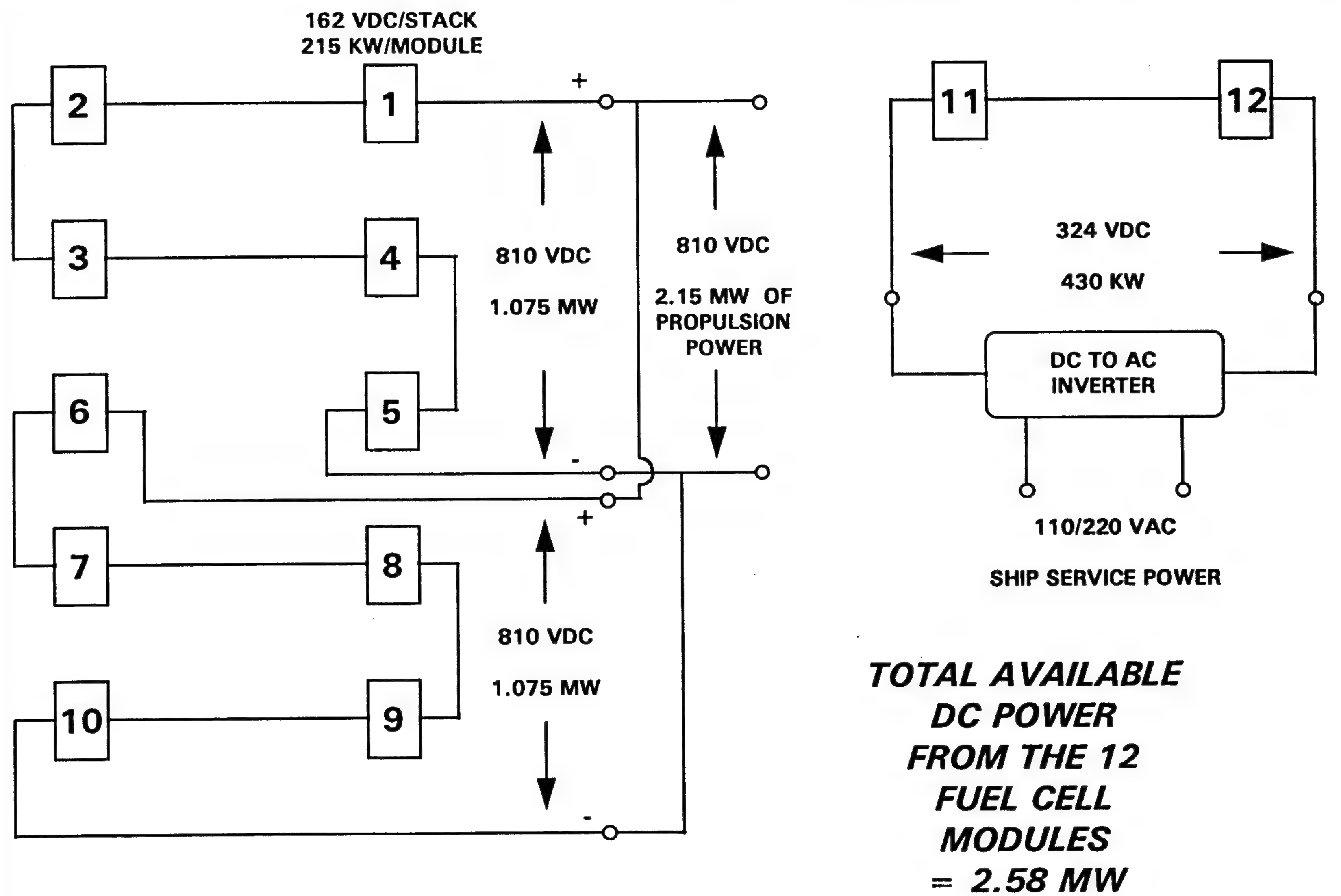


FIGURE 7-2 LIGHTSHIP WEIGHT REDUCTION

DIESEL ENGINE GEN. SYSTEM	FUEL CELL POWER SYSTEM
REMOVALS	**ADDITIONS**
127.8 LT	113.1 LT

NET RESULT

14.7 LT LESS

FIGURE 7-3 ADVANTAGES OF LIGHTSHIP WEIGHT REDUCTIONS

- LESS HIGH UP WEIGHT ------------------------------ NO STACKS ABOVE BRIDGE DECK AND NO EXHAUST SILENCERS REQUIRED
- LESS WEIGHT IN "ENGINE" ROOM -------------- NO SOUND ISOLATION "BEDPLATES" OR RAFTS REQUIRED
- LESS COOLING SYSTEM WEIGHT --------------- FUEL CELL MODULES ARE AIR COOLED
- NO REQUIREMENT FOR ENGINE LUBE OIL SYSTEM

FIGURE 7-4 FULL LOAD CONDITION WEIGHT REDUCTION

- REDUCED LUBE OIL REQUIRED ---------------- 7.1 LT VERSUS 34.4 LT

- DRAMATICALLY REDUCED FUEL LOAD FOR IDENTICAL 10,000 NM RANGE. ------ 175 LT LESS FUEL REQUIRED

THE ADVANTAGE OF THE 10,000 NM OPERATIONAL RANGE "FULL LOAD CONDITION" WEIGHT REDUCTION IS:

- 2 FEET LESS DRAFT, and therefore a

- 2 KNOT INCREASE IN TRANSIT SPEED

When the "Navy Configuration" T-AGOS ship VINDICATOR was made available to the USCG in the 1993 time period the original shipbuilder's weights for the various weight groups were applicable, including the Navy special mission equipment onboard. The USN Configuration is shown in Figure 7-5 with a lightship of 1,511 LT, the full load displacement of 2,296 LT and the resulting cruise speed of 12 knots.

Also shown in Figure 7-5 is the prospective fuel cell repowered VINDICATOR in the "USCG Configuration" at a lightship of 1,350 LT and the full load displacement of 1,953 LT. This lesser full load condition results in an estimated increase in the cruise speed of 2 knots to 14 knots. The power to the electric drive motors is not altered in this comparison. Furthermore, the nominal 10,000 NM range has been used for each of the configurations to define the needed fuel load.

7.2. Conclusions

AEL thus concludes from the results that a Preliminary Design Stage of the Project is now appropriate to demonstrate that sulfur-free diesel fuel cell modules will indeed perform as described in this feasibility study.

7.3 Recommendations

- This report provides strong evidence that the modularized DFC system is a very important means for USCG to aid in the environmental protection of the coastal zone as a key part of its "COAST GUARD" mission.

- In an effort to constructively find the near term funding resources for the USCG to demonstrate the DFC technology at-sea, it is recommended that the USCG consider fuel cells in all new cutter and buoy tender ship designs. The life cycle cost savings due to the reduced fuel consumption justify the capital investment in the superior technology of fuel cells.

- USCG-led efforts should continue at the interagency coordination level to put in place a Memorandum of Understanding (MOU) to cooperatively fund and advance the use of fuel cells in large "traction applications" such as the federal fleet of ships.

FIGURE 7-5 224 FT ELECTRIC DRIVE, FORMER US NAVY T-AGOS SHIP "VINDICATOR"

USN CONFIGURATION

DIESEL ELECTRIC, LIGHT SHIP	=	1,511 L TONS
FULL LOAD DISPLACEMENT	=	2,296 LT
CRUISE SPEED	=	12 KNOTS

USCG CONFIGURATION

FUEL CELL POWERED, LIGHT SHIP	=	1,350 LT
FULL LOAD DISPLACEMENT	=	1,953 LT
CRUISE SPEED (Est)	=	14 KNOTS

8. LIST OF REFERENCES

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15. PHYSICS FOR STUDENTS OF SCIENCE AND ENGINEERING. August 1965 text book on basic physics, which includes many science and engineering process calculations and constants. David Halliday, Professor of Physics University of Pittsburgh and Robert Resnick, Professor of Physics Rensselaer Polytechnical Institute. Copyrights John Wiley & Sons, Inc. 1962.

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APPENDIX A - FUEL CELL MODULE DESIGN

Explanatory text describes each drawing which is also identified by its APPENDIX A page number. The first drawing is a schematic block diagram of one fuel cell power module plus the generic "balance-of-plant" (BOP) needed for the multiple one-sided-fit modules. The balance of the AUTOCAD drawings provide mechanical details on the module.

1. DFC MARINE POWER PLANT BLOCK DIAGRAM A -11

This block diagram describes the one-sided-fit fuel cell power plant module. It will have a power output rating of about 210 kW DC at 162 Volts.

2. FUEL CELL 3-D VIEW SCALE TO FIT A -12

This AUTOCAD fuel cell module 3-D assembly drawing shows a number of the components involved. They include: The BASE, the COVER, the TOPPLLT (top plate), four TOP BRACKETs, four BASE BRACKETs and four LIFT RODS. The purpose of the TOP and BASE BRACKETs, which extend beyond the boundary of the COVER at the narrow ends of the assembly, are to provide 8 lift points for lifting in and out of the module. The purpose of the LIFT RODs is to hold the assembly together both longitudinally, laterally and vertically for lifting. The LIFT RODS are also used for precisely positioning and for securing the base of the module correctly at each physical interface with the new-built "deck" within the ship's "MAIN GENERATOR ROOM". The drawing shows the protective CASTLE NUTS which cover the threaded ends of the 4 LIFT RODS during transport and rigging into place of each module. Further details on the above module components follow.

3. MODULE ELEVATION VIEW (Untitled) A -13

This elevation view shows the components referred to above with respect to the line representing the surface of the new-built "deck" of the ship. The protective CASTLE NUTS would be removed prior to the module being "landed" on the "deck" so that the four module threaded LIFT RODS can be used to secure the module to the four per module internally threaded holes in the "deck" at each module position.

4. BASE PLAN VIEW SCALE TO FIT A -14

This drawing shows the top of the metal module BASE PLATE with major openings dimensioned. On the left the two square 6" x 6" openings are for the air inlet and the exhaust outlet connections. The two "small" circular openings are for water and fuel inlets respectively. To the right hand end of the BASE are 8 "smaller" internally threaded holes (located at the dimensions from the left hand edge of the base plate of 3' 0½", 3' 4½", 7' 4½" and 7' 8½" respectively). These holes match up with clearance holes in the fuel cell stack sub assembly which is discussed subsequently. The four "large" clearance holes at the extreme four corners of the base plate are for the lower shaft of each of the LIFT RODs to pass

through. The base BRACKETs center clearance holes are located over these clearance holes when in place. Each BASE BRACKET is secured to the base at its inner end by bolts which in turn thread into the "smallest" holes shown near to each corner. These "smallest" internally threaded holes are shown, for example, by the hole dimensioned at 6" to the right from the bottom left corner "large" base mounting clearance hole, which in turn is 1½" from the corner.

Around the periphery of the BASE are a series of 42 internally threaded "small" holes drilled in the sides of the BASE PLATE. These holes are for bolts which are used to secure the COVER, which is shown in the next drawing.

5. COVER 3-D VIEW SCALE TO FIT A -15

This drawing shows the metal module COVER. At the four corners the COVER is cut away to clear the LIFT RODs. The clearance bolt holes at the bottom edge of the COVER match up with the 42 threaded holes in the BASE PLATE, as referred to above. They are used to bolt the COVER to the BASE.

6. TOPPLT 3-D VIEW SCALE TO FIT A -16

This top metal plate sits on top of the COVER and has a clearance hole at each corner through which the four LIFT RODs pass. 6" from each corner hole in the drawing is shown a "small" threaded hole in the TOPPLT which is used to secure, with four bolts, the four TOP BRACKETs, which will be discussed further below. The purpose of the TOPPLT is to horizontally position the four top corner mounted lifting points directly above the four base corner mounted lifting points, as was previously shown in the Item 2 fuel cell module assembly drawing. The top metal plate is required during module transport and for rigging in and out. However, it can be removed once the module is in place.

7. TOP BRACKET A -17

This drawing shows the TOP BRACKET. Its 15° internally chamfered center hole is cut away, as shown, to permit its installation at the top end of the LIFT ROD. There is a smaller flange or "shoulder" near to the bottom of the LIFT ROD which can pass through the corner clearance hole in the TOPPLT but it cannot vertically pass through the diameter of the center chamfered clearance hole in the TOP BRACKET. The angle of the cut away is not perpendicular to the side of the TOP BRACKET, it is at an angle. This method prevents the TOP BRACKET, once in place at each corner of the TOPPLT and secured to the TOPPLT by its companion securing bolt (through the right hand end clearance hole shown in the drawing), from rotating in the horizontal plane around this securing bolt. The hole at the left hand end of the TOP BRACKET 3-D drawing is the rigging "lifting point" hole. The large top flange of the LIFT ROD holds down the TOP BRACKET and the external 15° chamfered upper segment of the LIFT ROD positions the ROD and secures the assembly.

8. <u>BASE BRACKET</u> A -18

The lift point purposes of this BRACKET shown in the 3-D drawing is similar to that of the TOP BRACKET except that it does not require a chamfered central hole. It still has an angled cut away for this hole, however to assist in assembly and disassembly. The angled cut away prevents its rotation in the horizontal plane. The left hand end clearance hole is the rigging "lifting point" hole.

9. <u>LIFT ROD</u> A -19

This 3-D drawing shows the LIFT ROD. Most of its functions have already been explained above. Just above the bottom externally threaded portion of this ROD is a short smaller diameter portion of the ROD around which a large "circlip" type of spring retaining "washer" can be fitted to keep the LIFT ROD vertically restrained while the fuel cell module is being landed in place. Just prior to the final positioning of a module close to the deck a series of four protective "castle nuts" are removed from the threaded bottom ends of the four RODs.

10. <u>CASTLE NUT</u> A -20

This device is used to protect the threaded bottom end of the LIFT RODs during all assembly, transport, lifting, positioning and other steps prior to the final positioning of the fuel cell module on location on the newly built ship "deck" in the ship's "MAIN GENERATOR ROOM" referred to earlier.

11. <u>BASE PLAN PERSPECTIVE VIEW (Untitled)</u> A -21

This drawing shows the fuel cell module BASE with the services openings highlighted. The 8 locating internally threaded holes for the positioning of the FOOT of the fuel cell stack are shown towards the right hand end of the drawing. The next series of drawings address the fuel cell stack and peripherals, all of which are located with respect to the BASE.

12. <u>FOOT THERMAL INSULATION</u> A -22

This perspective drawing shows the thermal insulation pad upon which the FOOT of the STACK is positioned. The drawing shows that the two corners to the right hand end of the pad are slightly relieved to clear the two BASE BRACKETs at the STACK end of the fuel cell module assembly. Because the fuel cell STACK operates at a high temperature the insulating pad is needed to prevent conduction of this heat (heat loss) from the STACK to the module BASE and in turn to the ship's "deck" where the module has been bolted down. Of the three grouped clearance holes shown in the drawing at each corner of the insulating pad the center shallow hole does not penetrate through the pad. The four shallow holes are used solely for the horizontal positioning the STACK FOOT above the FOOT THERMAL INSULATION pad.

13. STACK FOOT A -23

This drawing shows the metal STACK FOOT. The four center clearance holes (in the group of three clearance holes at each corner) are used for the bottom end of the STACK's vertical restraining STACK ASSEMBLY RODs, which are described subsequently. The STACK FOOT is held to the BASE PLATE by two bolts at each corner (8 places).

14. STACK OF CELLS (Untitled) A -24

This perspective drawing shows the STACK of 216 individual 9 square ft utility type fuel cells which sit upon the STACK FOOT. Based on 3 cells per inch and a 6 ft height (72") the 216 cells will each produce a nominal 0.75 Volts D.C. Therefore each 216 cell STACK will produce 162 Volts D.C.

15. STACK A -25

This perspective assembly drawing shows the 216 cells sitting on the STACK FOOT with a thin electrical insulating plate just above the surface of the STACK FOOT. The purpose of this electrical insulating plate is to electrically isolate the STACK from the STACK FOOT. An exactly analogous electrical insulating plate is placed on top of the uppermost cell in the 216 cell STACK. Although this insulating plate does not show in this perspective drawing, it is there. It electrically insulates the cell STACK from the metallic STACKTOP, which is shown. Because the STACKTOP and the STACKFOOT are held together with metallic STACK ASSEMBLY RODS at the four corners of the STACK assembly this three part electrical conducting path would be complete and would therefore short out the 162 Volts D.C. from the STACK. The purpose of the top and bottom insulating plates is thus to prevent this electrical "dead short" across the STACK.

16. STACK ASSEMBLY ROD A -26

This drawing shows the ROD which is threaded at both ends. Each top threaded end is inserted from below into the appropriate threaded corner hole in the STACKTOP. Each ROD's bottom end threaded portion passes through the appropriate corner clearance holes in the STACKFOOT. In a lower internal relieved portion of each of these STACKFOOT holes (not shown) are appropriate spring mechanism and retaining washers and nuts. They are used to compensate for the slight vertical differential thermal expansion rates of the STACK of 216 cells and that of each metallic ROD as a STACK assembly is brought from "room temperature" to 650° C operating temperature of the direct fuel cells (DFCs), or when cooled back down again once "turned off".

17. TOP THERMAL INSULATION FOR STACK A -27

The uppermost stack sub assembly shown is the TOP THERMAL INSULATION pad. Because it goes between the top of the hot STACK assembly and the module cover it has no corner clearance holes in it, as shown.

18. STACK ASSEMBLY A -28

This "Front View" of the STACK assembly could be said to have East, West, North and South "faces" where "East" is to the right of the drawing and "North" is to the top of this drawing. The "East" end of the stack (to the right in this drawing) is identifiable by the relieved bottom right front corner of the FOOT INSULATION PAD, below the STACK FOOT. This descriptive compass type convention will be used in the discussion of the following various manifolds on the STACK and the electrical insulators between the stack and the individual manifolds.

19. ANODE INLET MANIFOLD ELECTRICAL INSULATION A -29

The four sides of the STACK must be electrically insulated to prevent shorting of the 162 volt output from the 216 cells in the STACK by the electrical conducting metal manifolds which will be attached to the four sides of the STACK. The first of these manifolds electrical insulators is for the Anode inlet on the "West" side of the STACK.

20. CATHODE INLET MANIFOLD ELECTRICAL INSULATION A -30

This peripheral electrical insulation is used on the "North" side of the STACK.

21. ANODE OUTLET MANIFOLD ELECTRICAL INSULATION A -31

This electrical insulation is used on the "East" side of the STACK.

22. CATHODE OUTLET MANIFOLD ELECTRICAL INSULATION A -32

The fourth electrical manifold insulator is for the cathode outlet, on the "South" side of the STACK.

23. ANODE INLET, ANODE OUTLET, CATHODE INLET, CATHODE OUTLET. ELECTRICAL INSULATION PLATES (Wire Frame View) A -33

The four manifold electrical insulation plates are shown in their perspective "wire frame" view from the "South" side of the STACK.

24. ANODE INLET, ANODE OUTLET, CATHODE INLET, CATHODE OUTLET ELECTRICAL INSULATION PLATES (Hidden Line View) A -34

This drawing shows the four manifold electrical insulation plates in a "hidden line" view. The next part of the assembly of the STACK involves the manifold themselves.

25. <u>ANODE INLET MANIFOLD</u> A -35

This perspective drawing shows the hollow metallic manifold which covers the ANODE INLET corner of the previously described stack of 216 cells. Using the above explained East/West and North/South compass convention to describe the faces of the STACK of 216 cells, the ANODE INLET manifold is on the "West" face and anode feed gas enters the "Northwest corner" of the STACK. This manifold can be identified by the circular inlet opening.

26. <u>STACK WITH CATHODE INLET MANIFOLD</u> A -36

The CATHODE INLET MANIFOLD is shown in this perspective view on the "South" side of the STACK of 216 cells. In this "North" side view no ANODE INLET MANIFOLD is shown on the "Northwest" corner of the STACK. Anode gasses flow through the cells from the "Northwest" corner to the "Southeast" corner of the STACK. The ANODE OUTLET from the STACK will therefore be on the "opposite side" i.e. at the "Southeast" corner of the "East" face of the STACK. As can be deduced from the previous Item 1 description of the POWER PLANT BLOCK DIAGRAM, the ANODE OUTLET gas flow is fed "around the corner" to the CATHODE INLET MANIFOLD, which is on the "South" face of the STACK, as shown at the top of this drawing. The CATHODE INLET MANIFOLD can be identified by its square inlet opening.

27. <u>CATHODE INLET COMBINED WITH ANODE INLET</u> A -37

This perspective drawing shows the ANODE INLET and the CATHODE INLET MANIFOLDS but as seen from the "North" side of the STACK. The location where the vertical edges of the ANODE INLET and of the CATHODE INLET MANIFOLDs come into close proximity, in this case at the Southwest corner of the STACK, is shown at the top of the STACK.

28. <u>CORNER DETAIL (ANODE INLET AND CATHODE INLET (Common Corner/Edge)</u>
A -38

The top corner of the Southwest corner/edge of the STACK is shown in this perspective detail drawing. In this drawing the MANIFOLD sheet metal material is 1/16" thick. Each metallic MANIFOLD is held away from the faces of the STACK by the previously described 1/16" thick electrical insulation plates (not shown) so as to prevent electrical shorting of the STACK by the electrically conductive manifolds. The technical means to retain the two MANIFOLD corners together is analogous to a series of "C clamp" or "binder clip" type spring clips which pinch and hold the two corner edge members together. These corner spring clips are, however, not shown in this detail drawing.

29. <u>ANODE INLET & CATHODE INLET MANIFOLDS ON STACK</u> A -39

In this "West View" drawing the two inlet MANIFOLDS are shown on the STACK assembly (minus the STACK ASSEMBLY RODS). The STACK assembly, in turn, is shown in its location on the right hand (East) end of the module BASE PLATE.

30. <u>CATHODE OUTLET MANIFOLD</u> A -40

The hollow sheet metal CATHODE OUTLET MANIFOLD is shown in this "Front View" drawing without the STACK and other sub assemblies present. The outlet of this manifold is shown with a square outlet flange, which will in turn be connected to one of the heat exchanger (not shown).

31. <u>STACK WITH CATHODE OUTLET MANIFOLD</u> A -41

In this "Front View" drawing the CATHODE OUTLET MANIFOLD, attached to the back of the cell STACK is shown in conjunction with the STACK of 216 cells. Also shown in this view are the thin but important STACK electrical insulating plates at both the bottom of, and on the top of, the cell STACK.

32. <u>CATHODE INLET AND CATHODE OUTLET MANIFOLDS ON STACK</u> A -42

This perspective view shows the stack at its location on the "East" end of the BASE PLATE. Both CATHODE MANIFOLDS are shown in place on the STACK, but with the STACK TOP not shown nor the STACK ASSEMBLY RODS. The next module design aspect involves the "balance of plant" equipment within the module, namely, the two heat exchangers and the adiabatic converter, as shown in the Item 1 schematic drawing.

33. <u>SUPPORT LEGS FOR BOTH HEAT EXCHANGERS</u> A -43

Referring again to the Item 1 BLOCK DIAGRAM (A -) the cathode exhaust heat is transferred to the incoming air as well as to the fuel and water to vaporize these two "reactants". The support legs shown in the drawing secure the lower (air) HEAT EXCHANGER and the upper (fuel and water) HEAT EXCHANGER.

34. <u>HEAT EXCHANGER FOR CATHODE INLET AIR (Wire Frame View)</u> A -44

This lower HEAT EXCHANGER is shown in the perspective wire frame drawing (a front view) wit the square openings on the "West" and "East" faces for the inlet horizontal air flow West-to-East. The top surface and the bottom surface of the HEAT EXCHANGER also have square openings. These are for the downward cross flow of the hot exhaust gasses from which the heat transfer occurs.

35. <u>HEAT EXCHANGER FOR CATHODE INLET AIR (Hidden Line View)</u> A -45

This hidden line perspective view drawing shows the same HEAT EXCHANGER as above with its openings incorporating manifold flange mating surface bolt holes (4 per flange) and the mounting bolt holes for the SUPPORT LEGS.

36. <u>KNEE DUCT</u> A -46

This is the nominal 6" x 6" square air inlet duct from the BASE to the CATHODE INLET AIR HEAT EXCHANGER's square opening on the "West" face.

37. <u>HORIZONTAL DUCT</u> A -47

This short square HORIZONTAL DUCT connects the square cathode air outlet of the HEAT EXCHANGER to the nominal 6" x 6" square inlet opening of the CATHODE INLET MANIFOLD.

38. <u>VERTICAL DUCT</u> A -48

This short nominal 6" x 6" square opening VERTICAL DUCT connects the exhaust gas flow from the upper HEAT EXCHANGER to the CATHODE INLET AIR HEAT EXCHANGER's top surface square duct opening.

39. <u>ANGLE DUCT</u> A -49

This nominal 6" x 6" square duct connects the opening on the bottom surface of the CATHODE INLET AIR HEAT EXCHANGER to the exhaust gas square opening in the BASE PLATE.

40. <u>HEAT EXCHANGER FOR FUEL AND WATER VAPORIZATION (Wire Frame)</u>
A -50

This wire frame view perspective drawing shows the upper HEAT EXCHANGER with its cathode exhaust flow square duct opening on the top surface. This drawing also shows the corresponding cathode exhaust flow square opening on the bottom surface of this HEAT EXCHANGER that mates with the above mentioned Item 38 VERTICAL DUCT. The cathode exhaust gas flow comes via the CATHODE OUTLET MANIFOLD as was described above in Item 30. The two small pipe openings shown on the "West" face of this HEAT EXCHANGER are for the water and fuel lines. Also shown on the "East" face are the steam and vaporized fuel pipes which come from cross flow through this HEAT EXCHANGER drawing heat from the vertical (downward) flow of cathode exhaust gas path. The holes shown on the "North" and "South" faces of this HEAT EXCHANGER are the mounting bolt holes to secure this Item to the two SUPPORT LEGS described in Item 33.

41. HEAT EXCHANGER FOR FUEL AND WATER VAPORIZATION (Hidden Line) A -51

The hidden line view drawing shows how this upper HEAT EXCHANGER would appear from the outside.

42. FUEL PIPE A -52

This flanged vertical pipe connects the fuel line opening on the BASE PLATE with the fuel line input flange on the "West" face of the above described upper HEAT EXCHANGER.

43. WATER INLET PIPE A -53

This flanged pipe connects the water inlet opening of the BASE PLATE to the water inlet flange on the "West" face of the upper HEAT EXCHANGER.

44. VAPORIZED FUEL PIPE A -54

The outlet of vaporized fuel from the upper HEAT EXCHANGER is piped over to the fuel inlet of the ADIABATIC COLUMN with this flanged section of pipe.

45. STEAM PIPE A -55

The vaporized water (steam) from the upper HEAT EXCHANGER is piped over to the steam inlet of the ADIABATIC COLUMN with this flanged section of pipe.

46. ADIABATIC COLUMN WITH SUPPORT LEGS A -56

Referring again to the Item 1 BLOCK DIAGRAM, this catalytic ADIABATIC COLUMN thermochemical device is used to change the vaporized diesel type complex molecule fuel into synthetic methane (CH_4) and carbon dioxide (CO_2) as well as, most importantly, to prevent the formation of any soot i.e. elemental carbon. This figure shows the ADIABATIC COLUMN with the upper steam and vaporized fuel pipe flanged inlet connections plus the larger diameter flanged outlet connection. This outlet connection feeds the resulting gas stream to the Item 25 ANODE INLET MANIFOLD. The ADIABATIC COLUMN has three supporting legs to position and secure this equipment to the BASE PLATE.

47. METHANE AND CARBON DIOXIDE PIPE FOR OUTPUT FROM ADIABATIC COLUMN A -57

This circular cross section short horizontal pipe takes the modified fuel stream from the ADIABATIC COLUMN outlet over to the circular flange on the ANODE INLET MANIFOLD.

48. FUEL CELL MODULE VERTICAL SECTION (Untitled) A -58

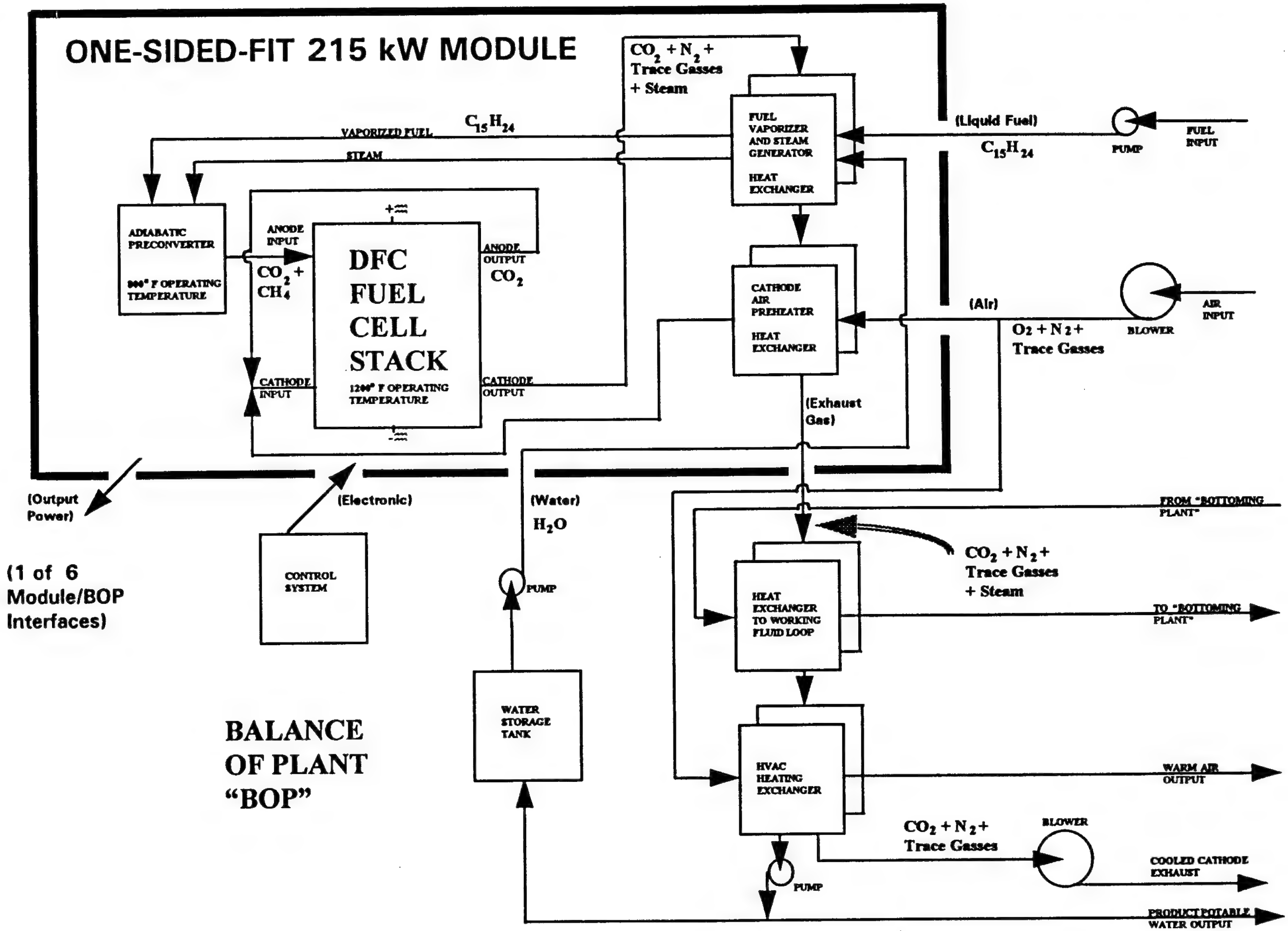
This view from the "South" side of the module shows all the previously identified and explained items, minus the STACK TOP and the STACK ASSEMBLY RODS and their securing nuts and washers. There are no vertical interferences between any of the components of the module.

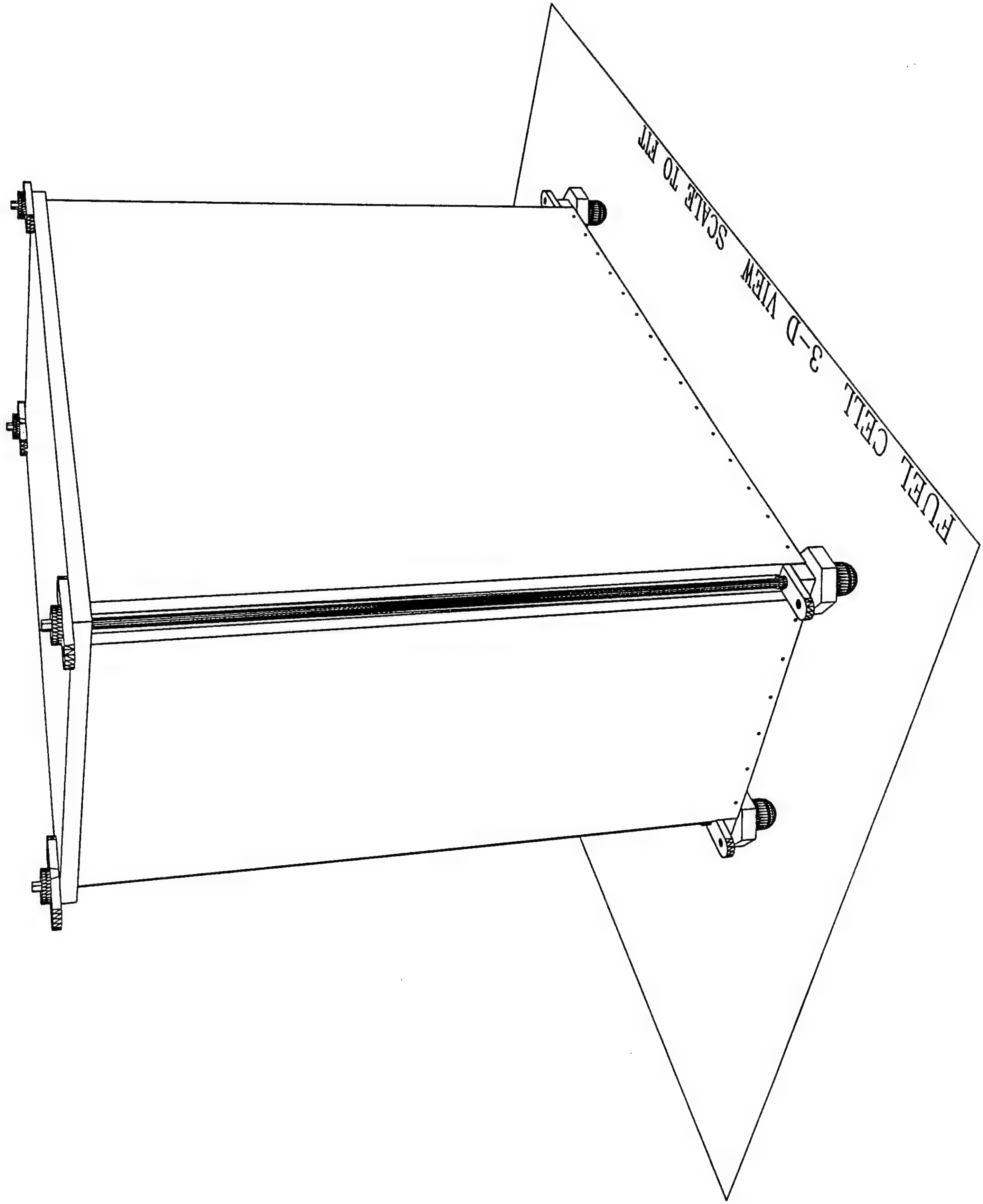
49. FUEL CELL MODULE PLAN VIEW (Untitled) A -59

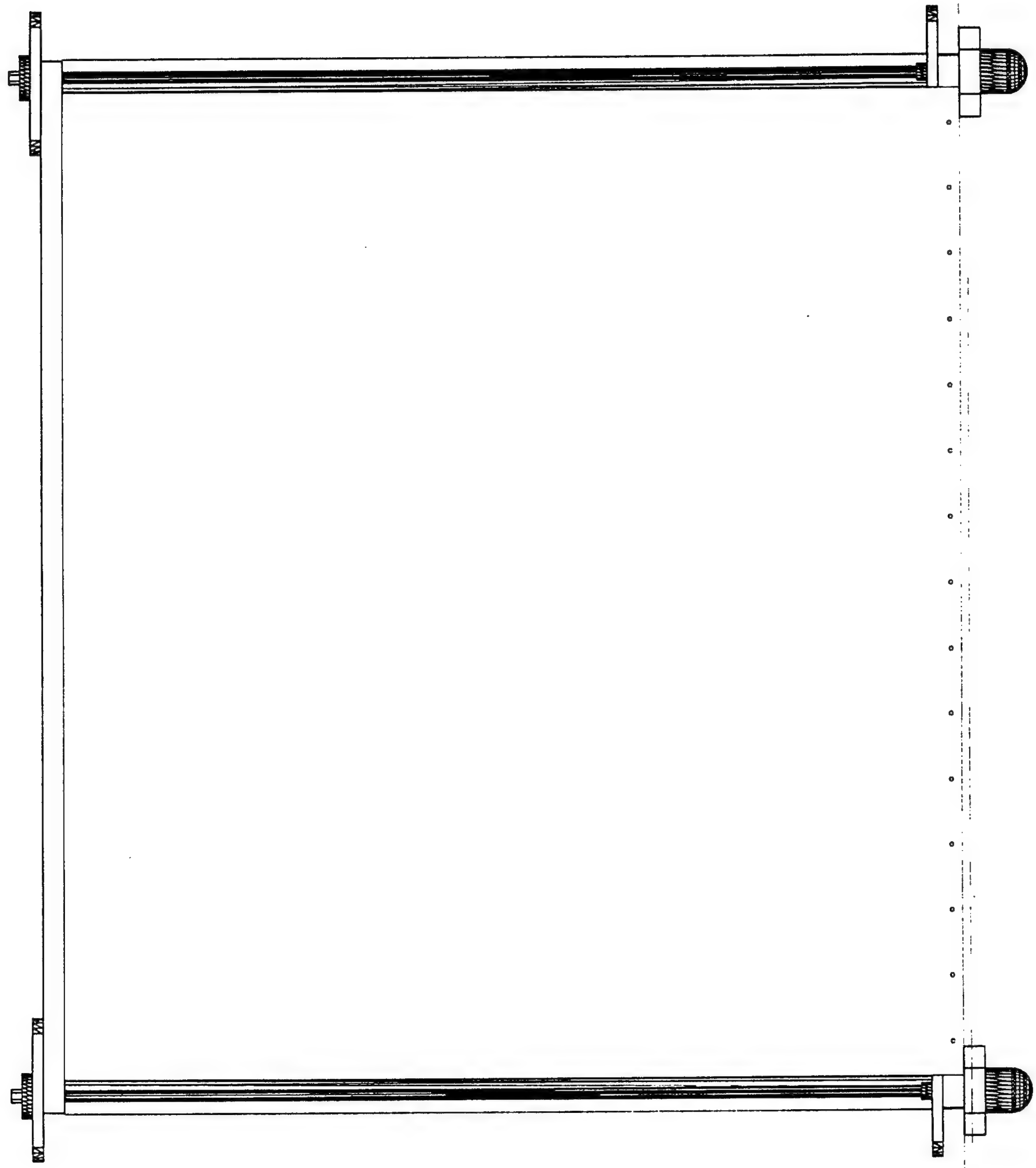
This top view of the assembly, again without the STACK TOP and the STACK ASSEMBLY RODS, shows all the relevant items in their respective horizontal positions. There are no horizontal interferences between any of the components of the module.

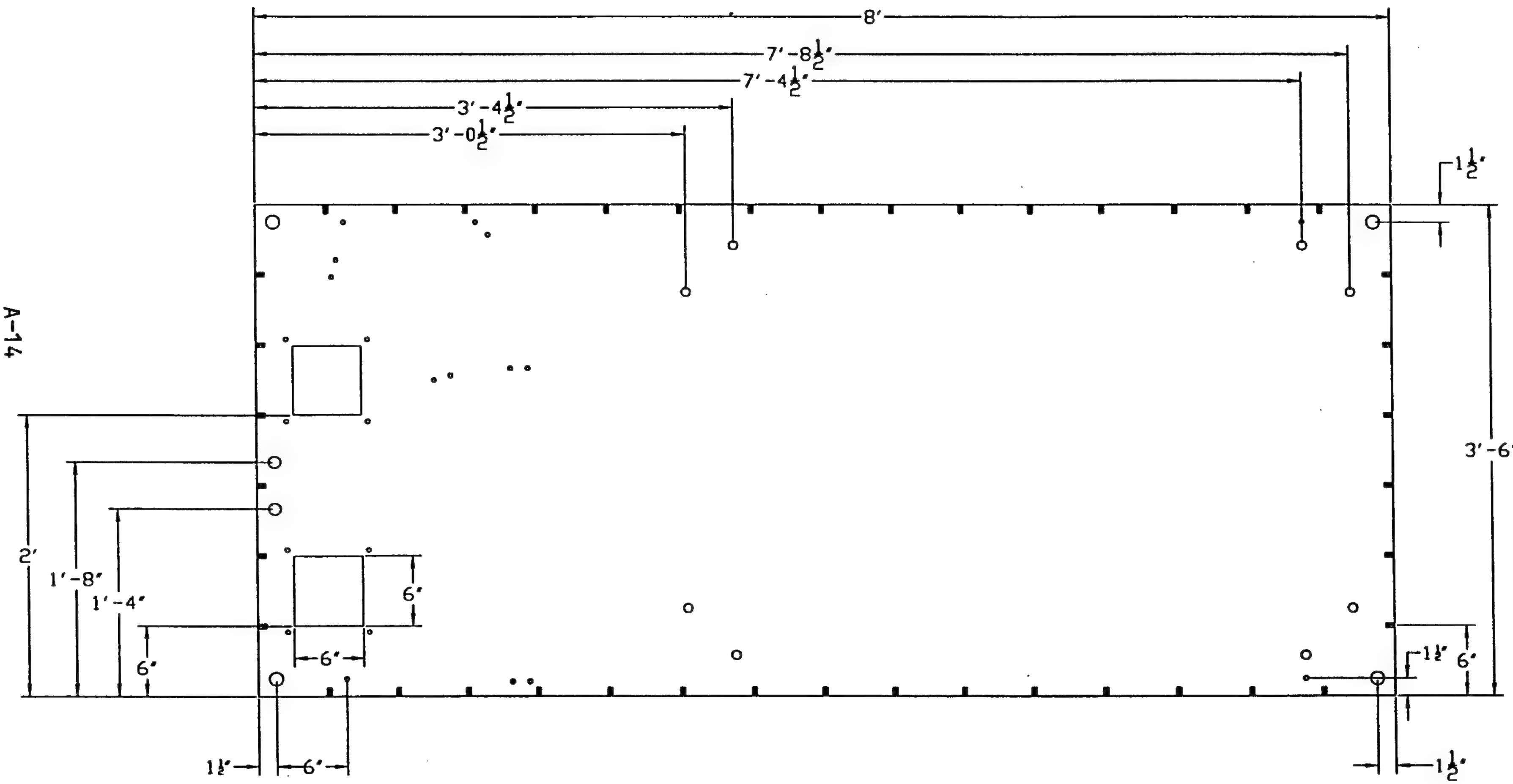
The Figures for the above Items follow this descriptive material in order. The AUTOCAD drawings provide considerable detail on each of the Fuel Cell Power Plant Module components.

DFC MARINE POWER PLANT BLOCK DIAGRAM

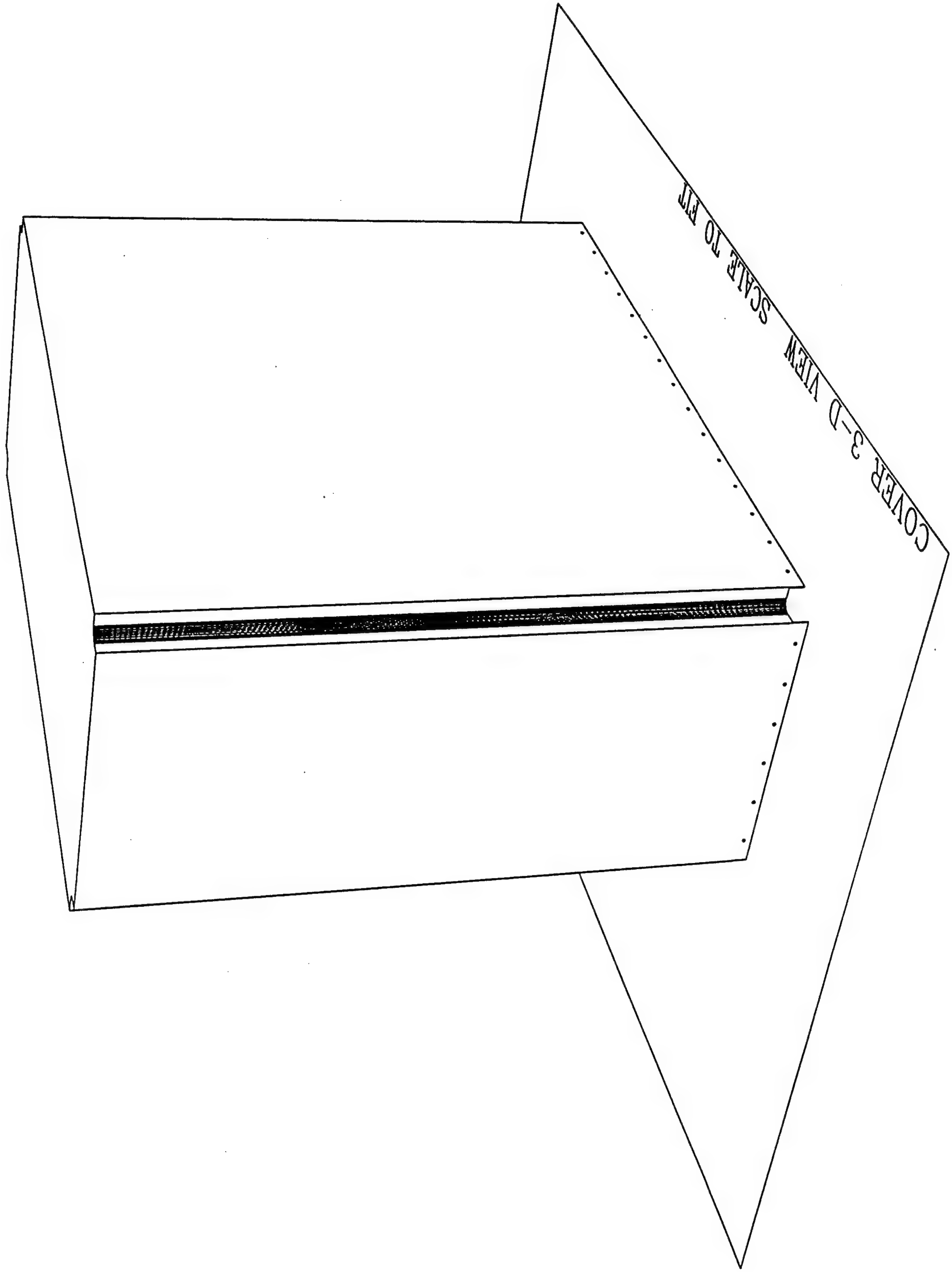



FUEL CELL 3-D VIEW SCALE TO FIT





BASE PLAN VIEW SCALE TO FIT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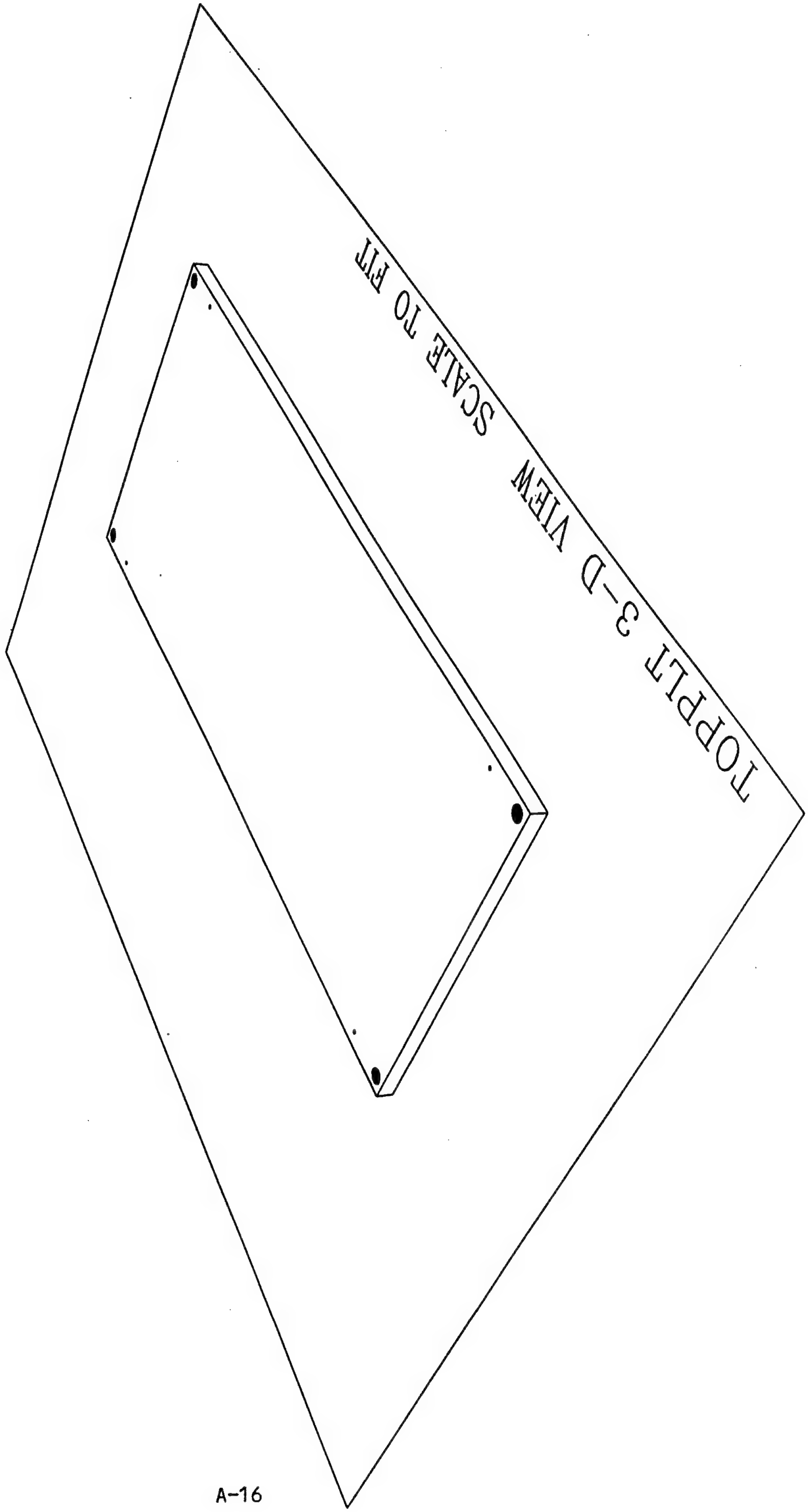
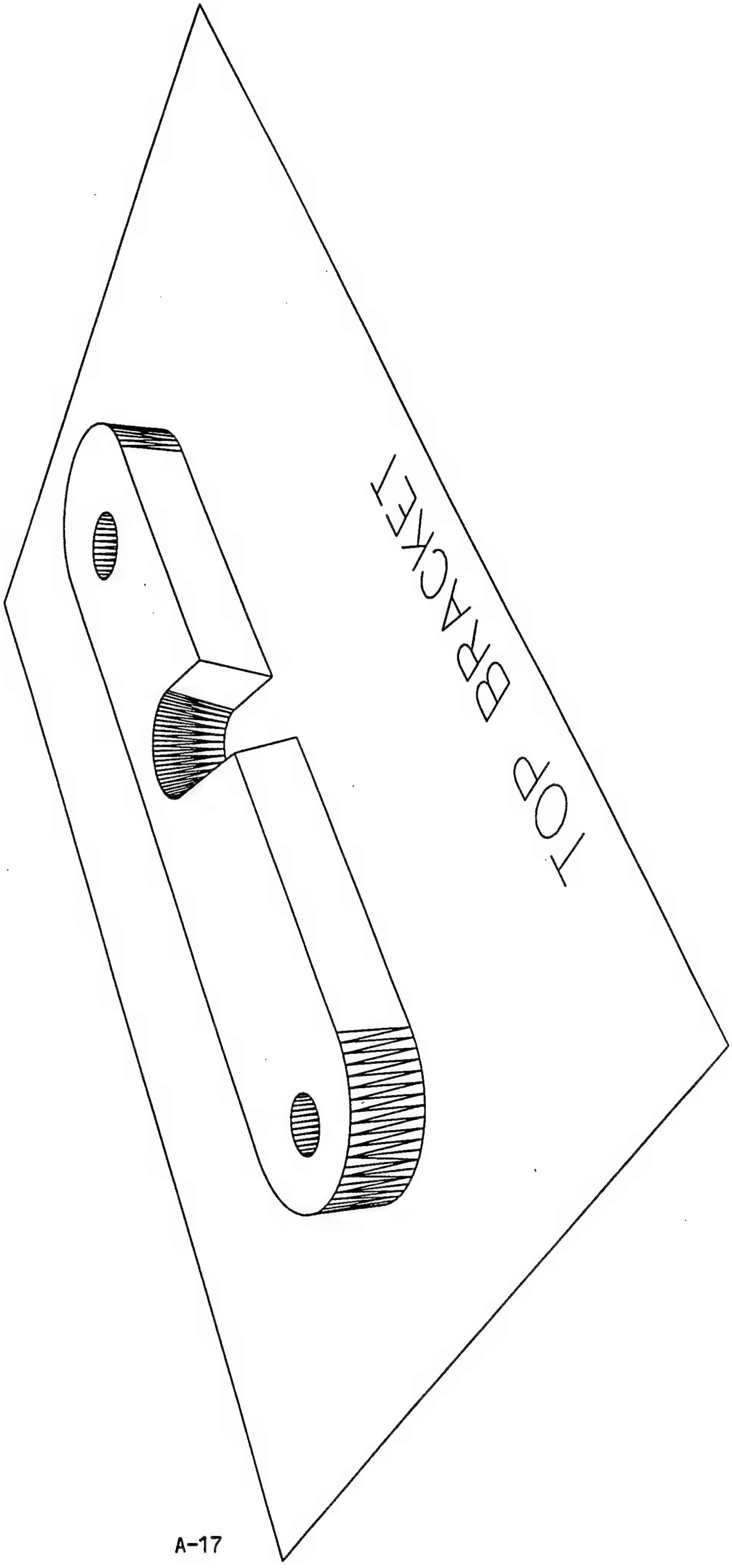
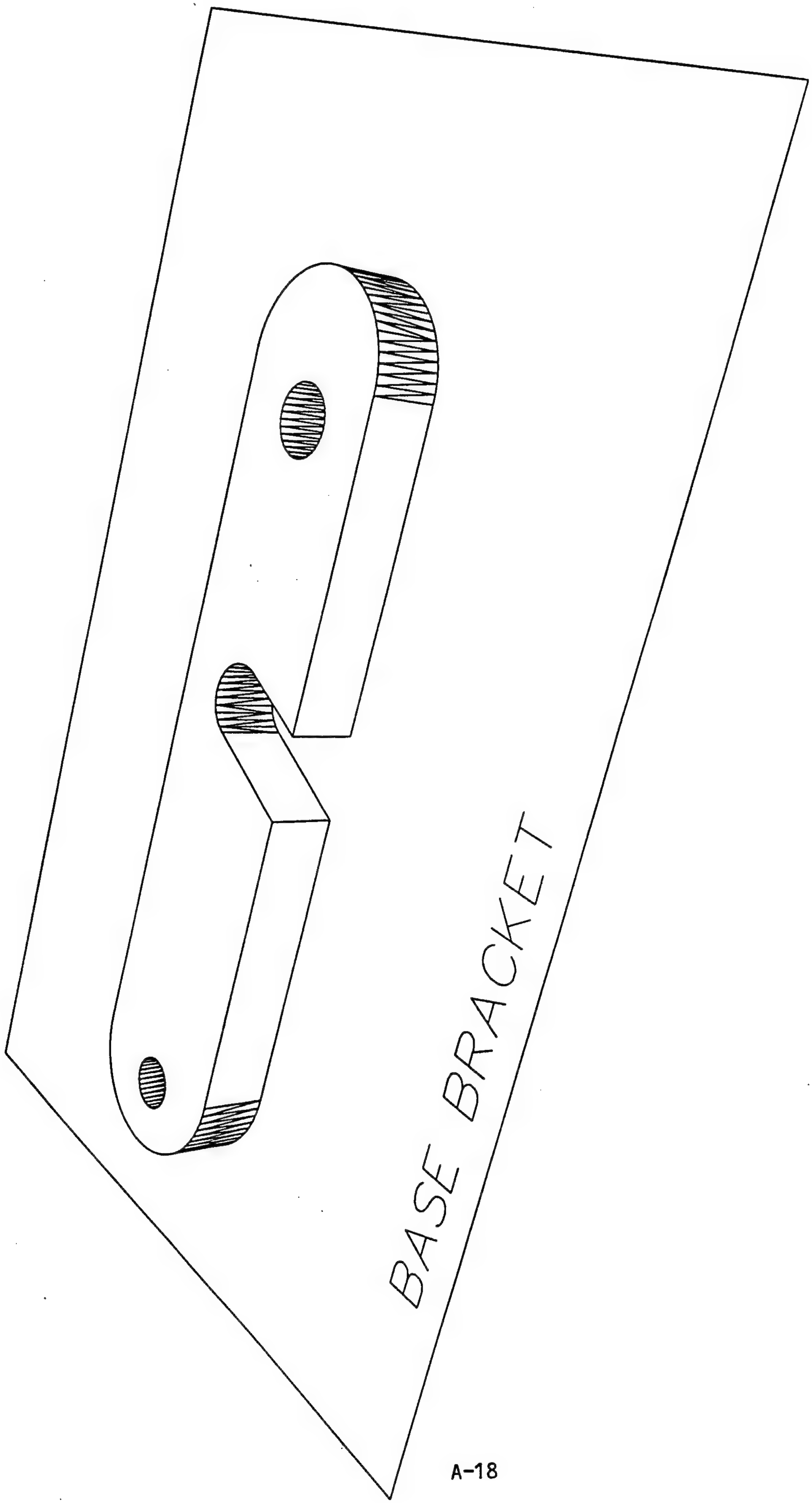
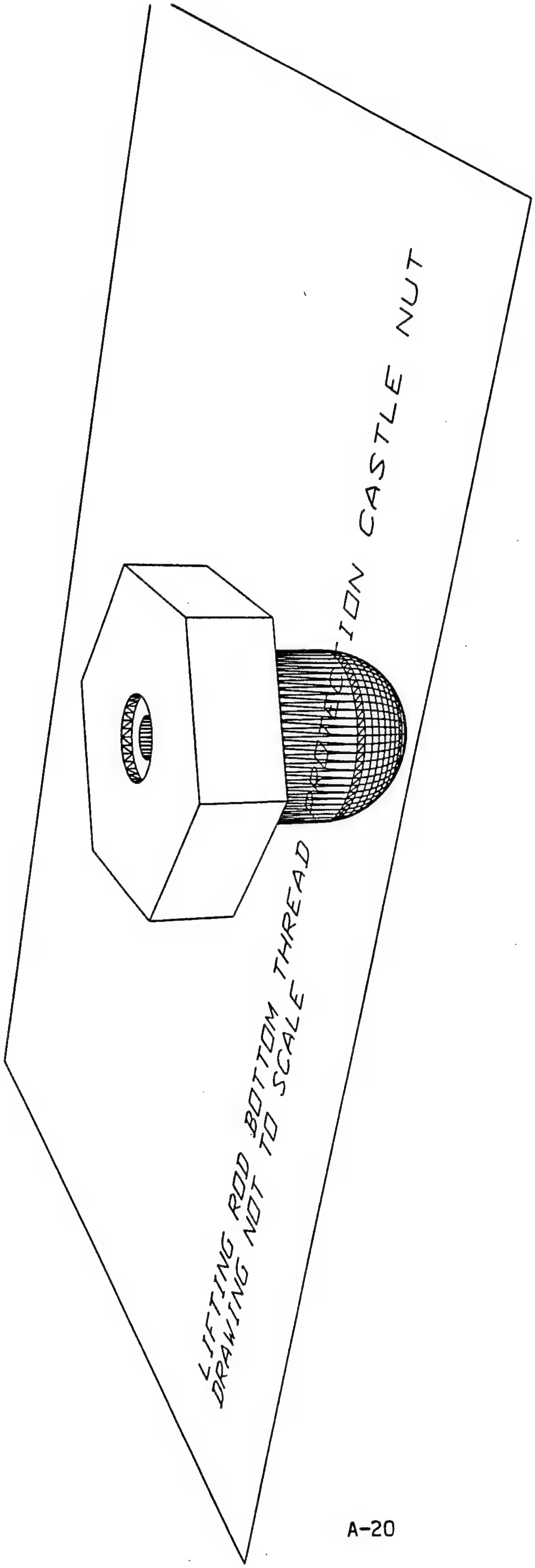
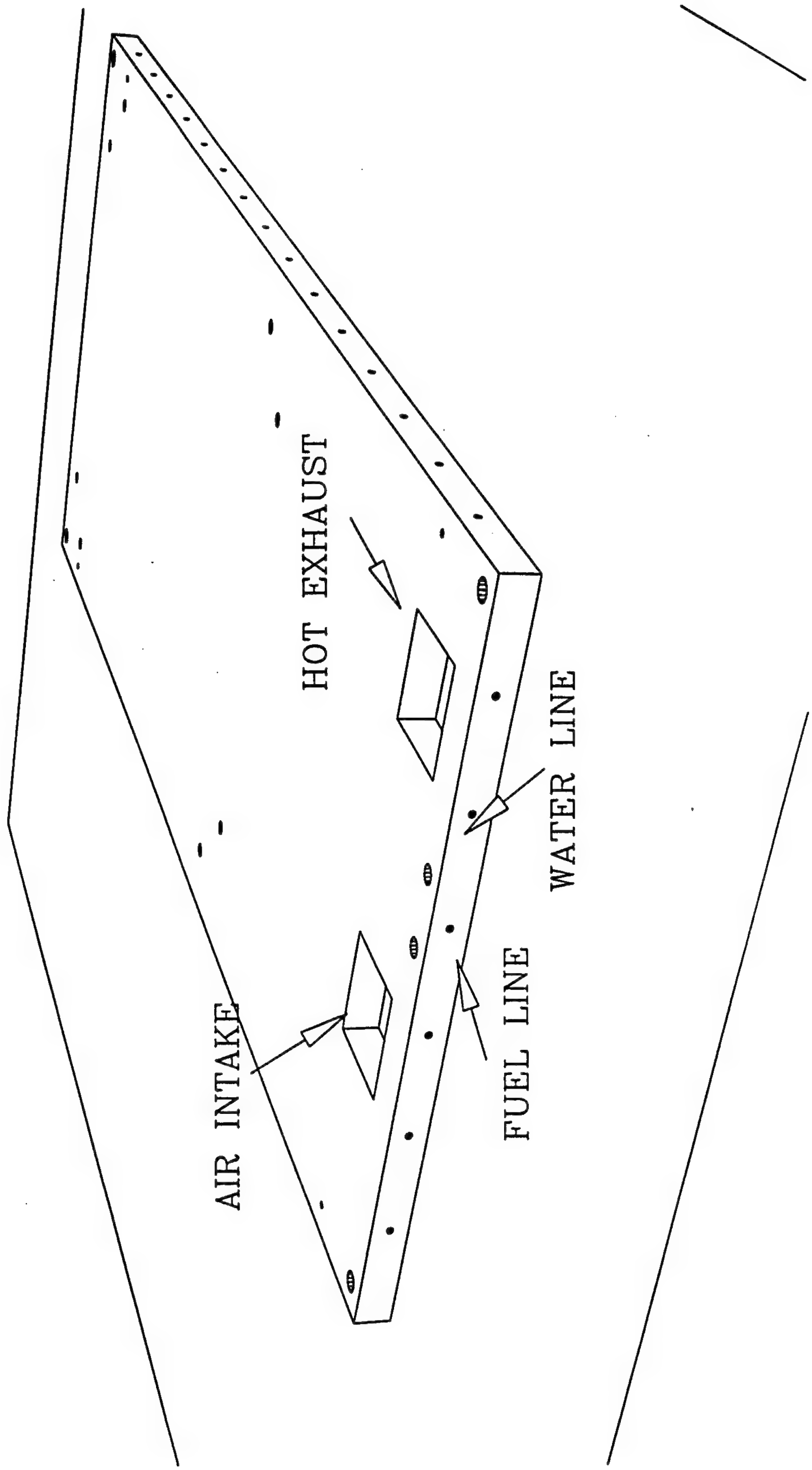

TOPPLT 3-D VIEW
SCALE TO FIT

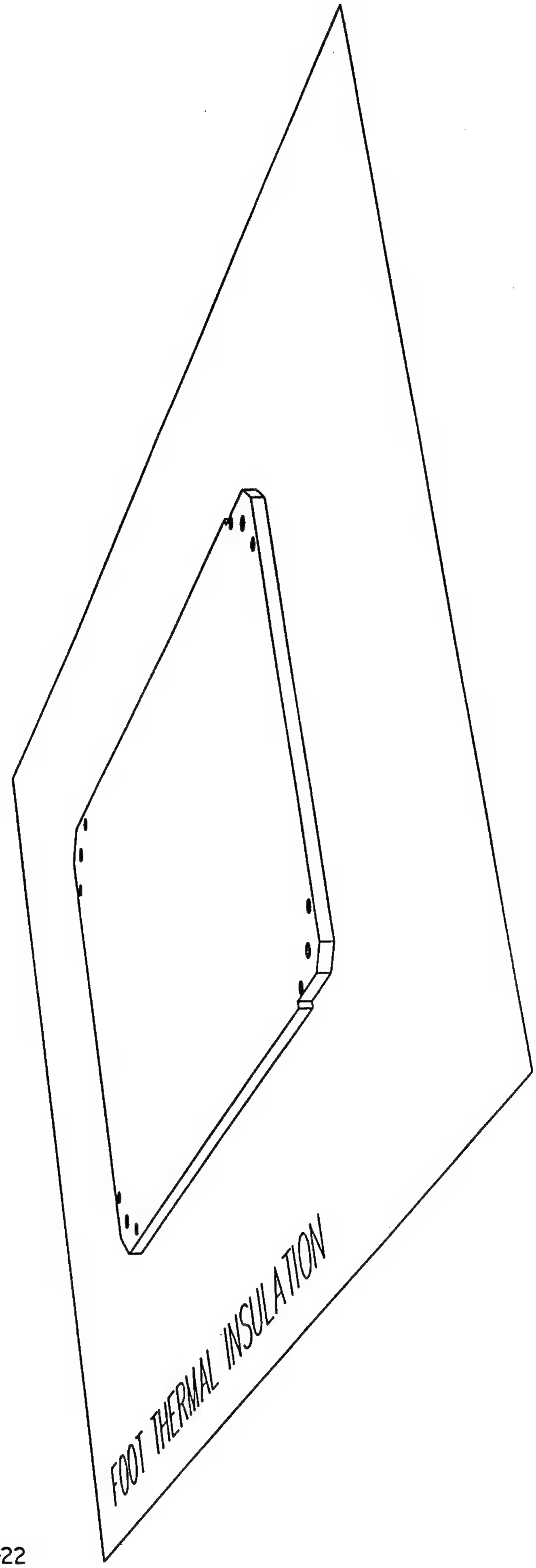

TOP BRACKET

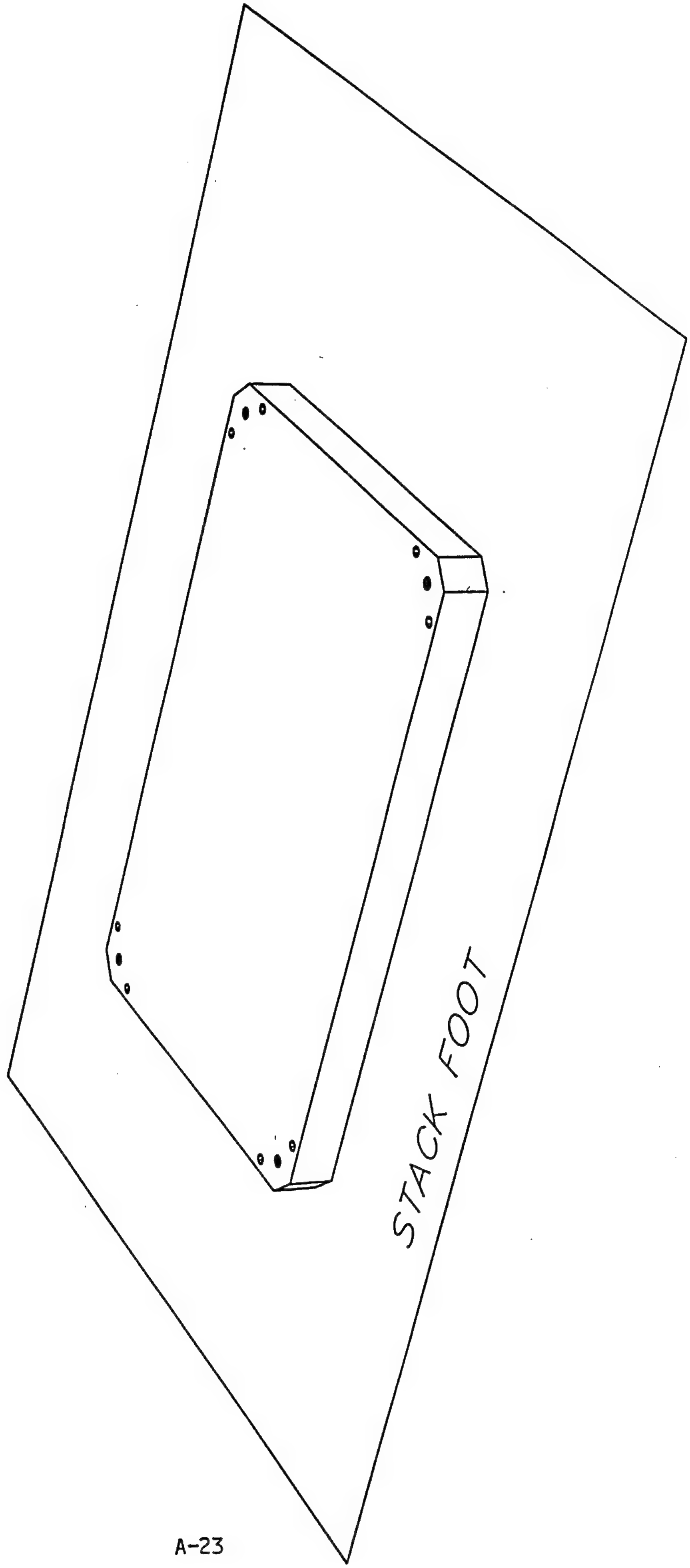

BASE BRACKET

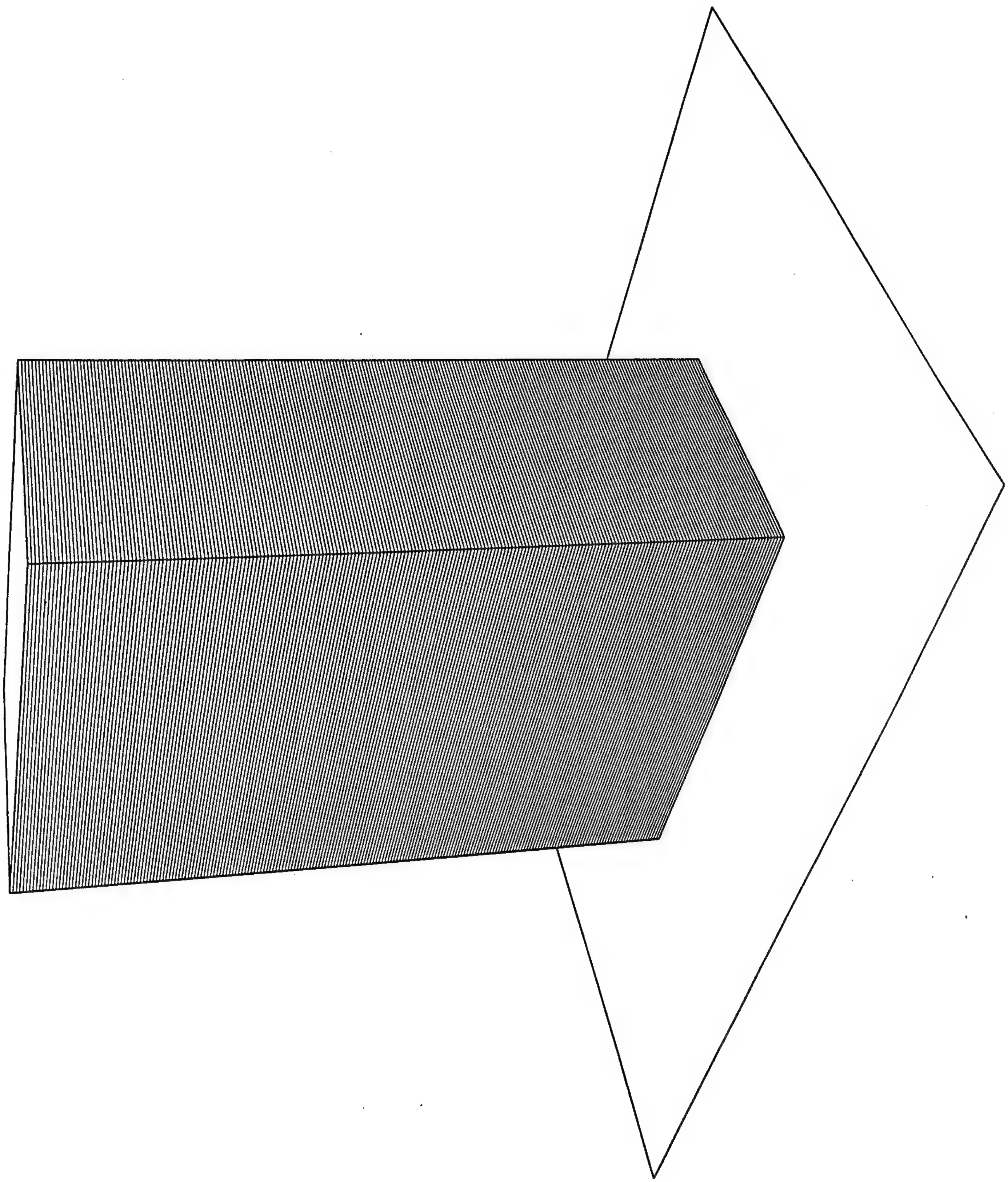
LIFT ROD

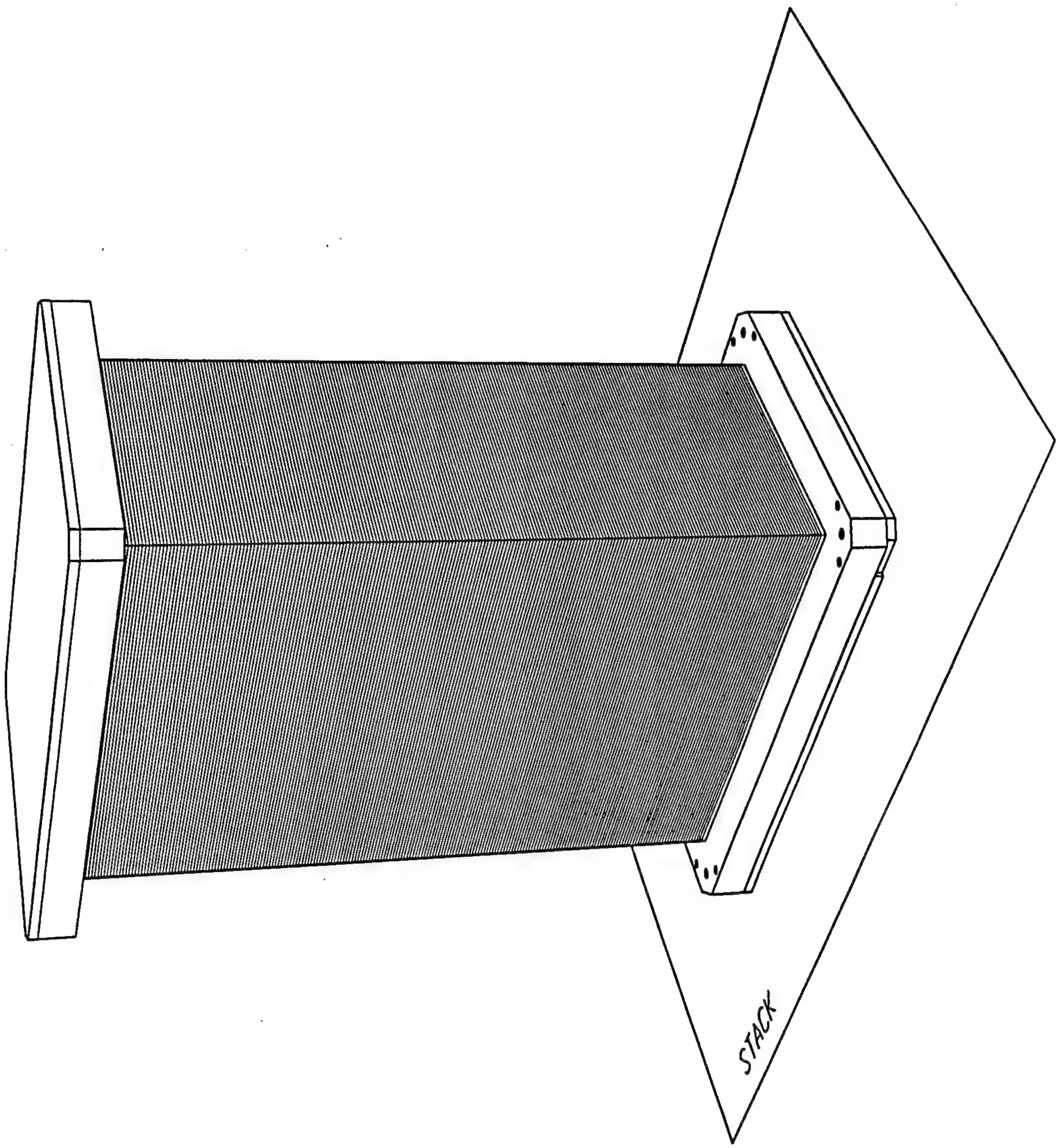

LIFTING ROD BOTTOM THREAD
DRAWING NOT TO SCALE
CASTLE NUT

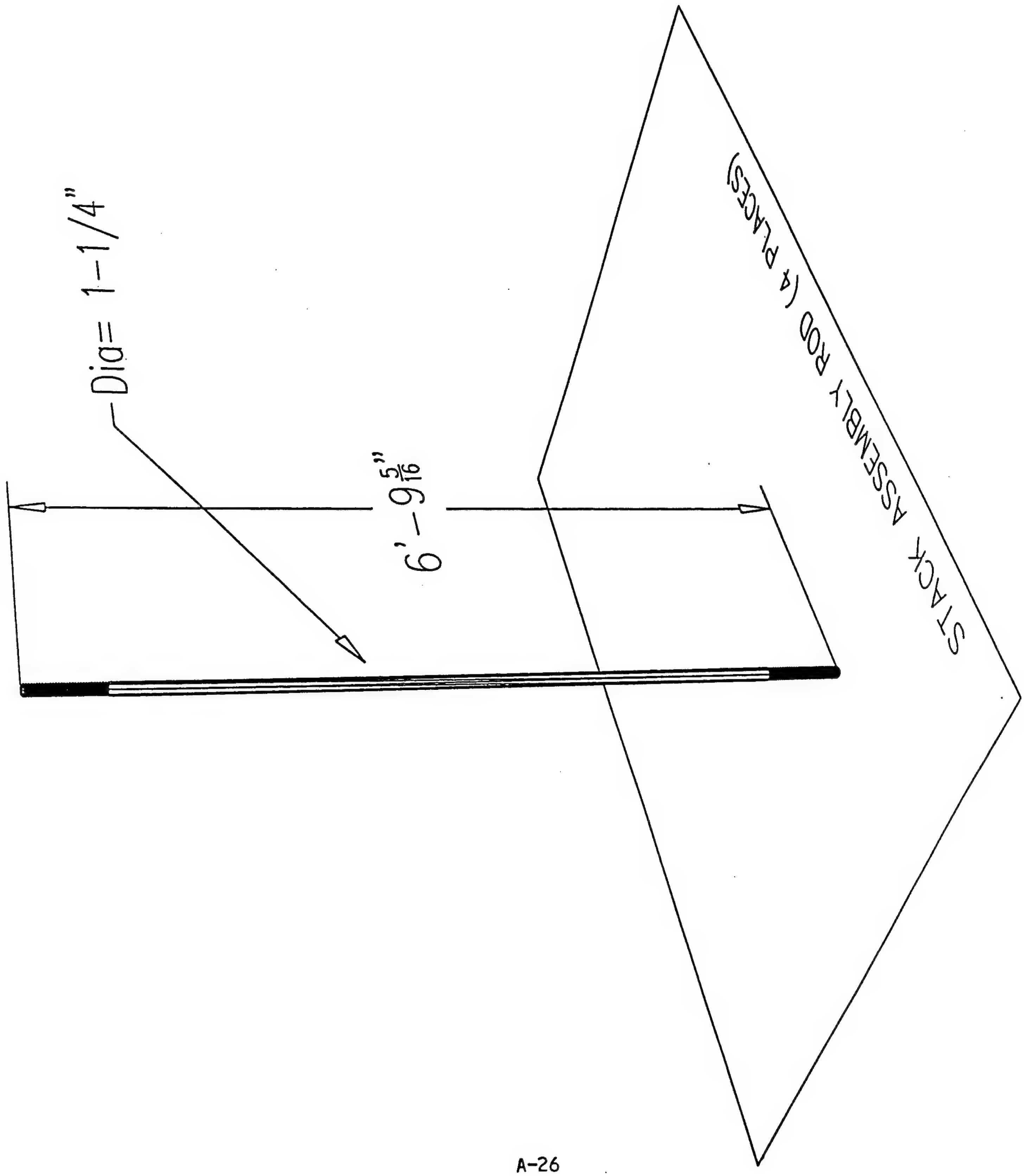

HOT EXHAUST
WATER LINE
AIR INTAKE
FUEL LINE

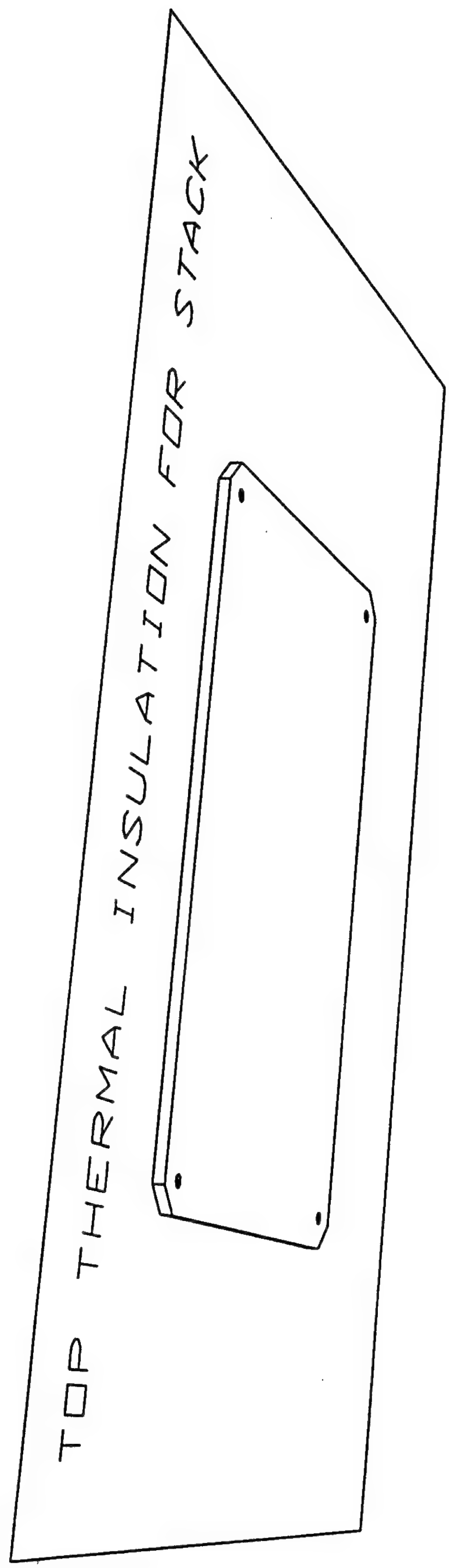

FOOT THERMAL INSULATION

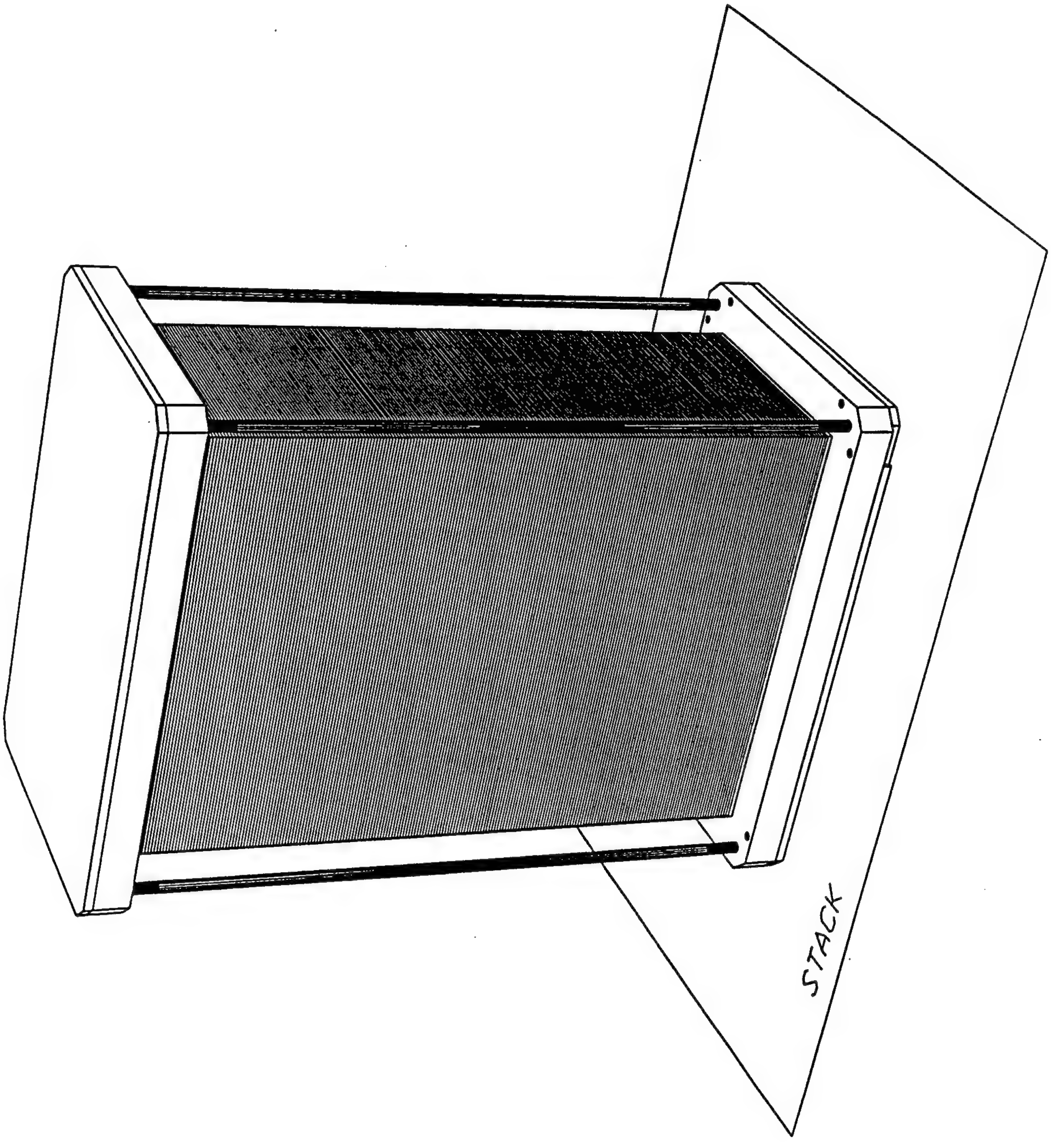

STACK FOOT

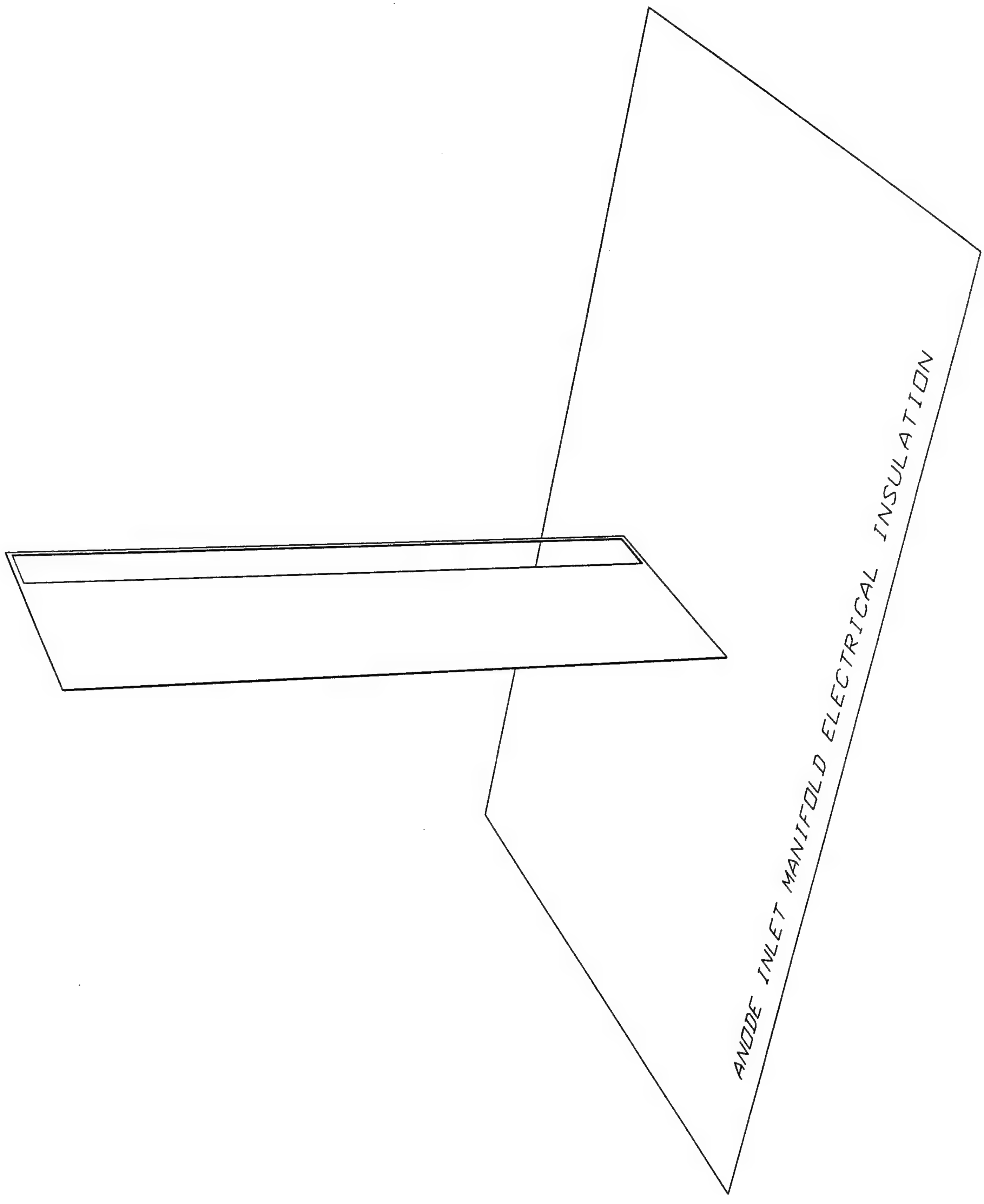


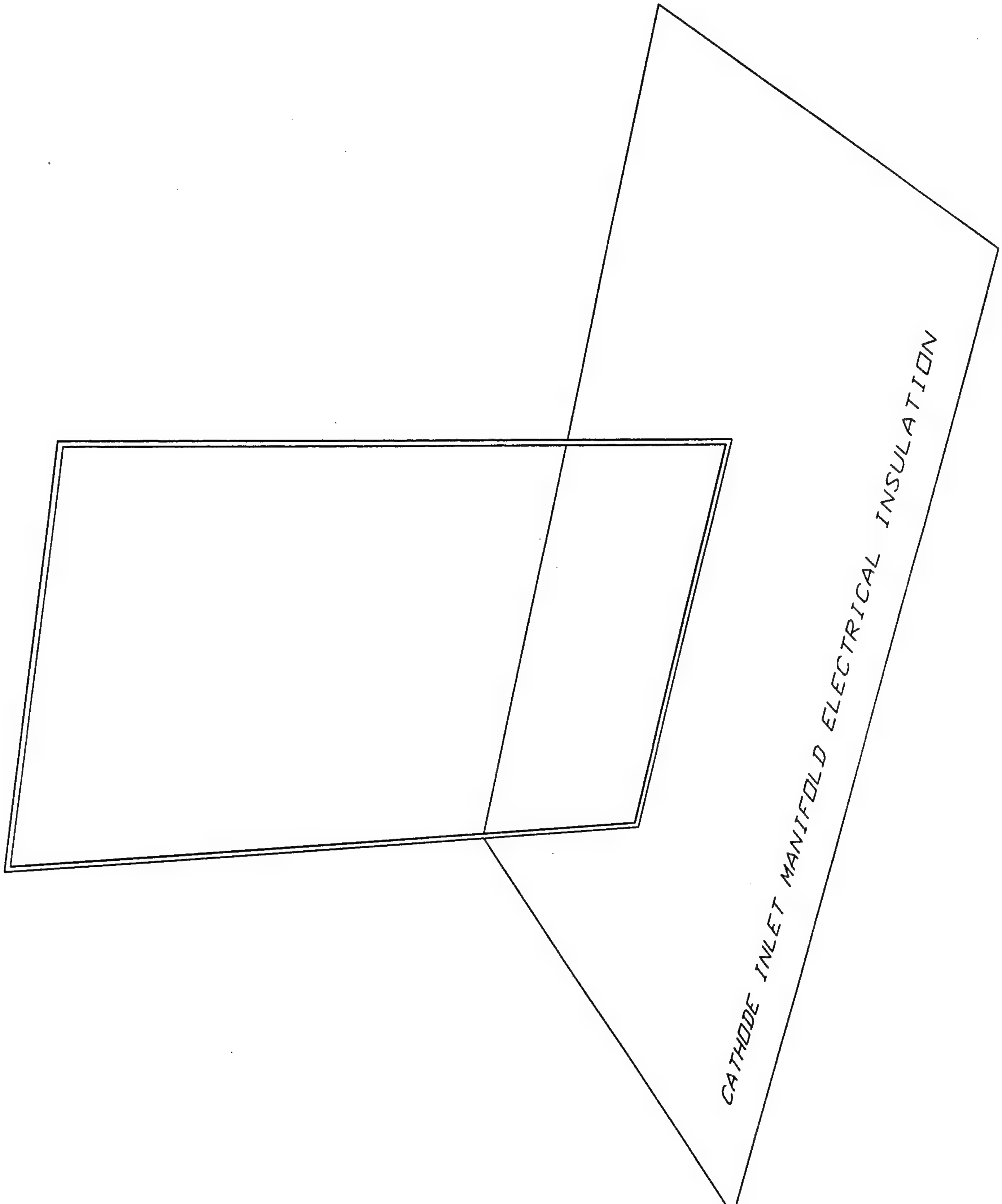

STACK

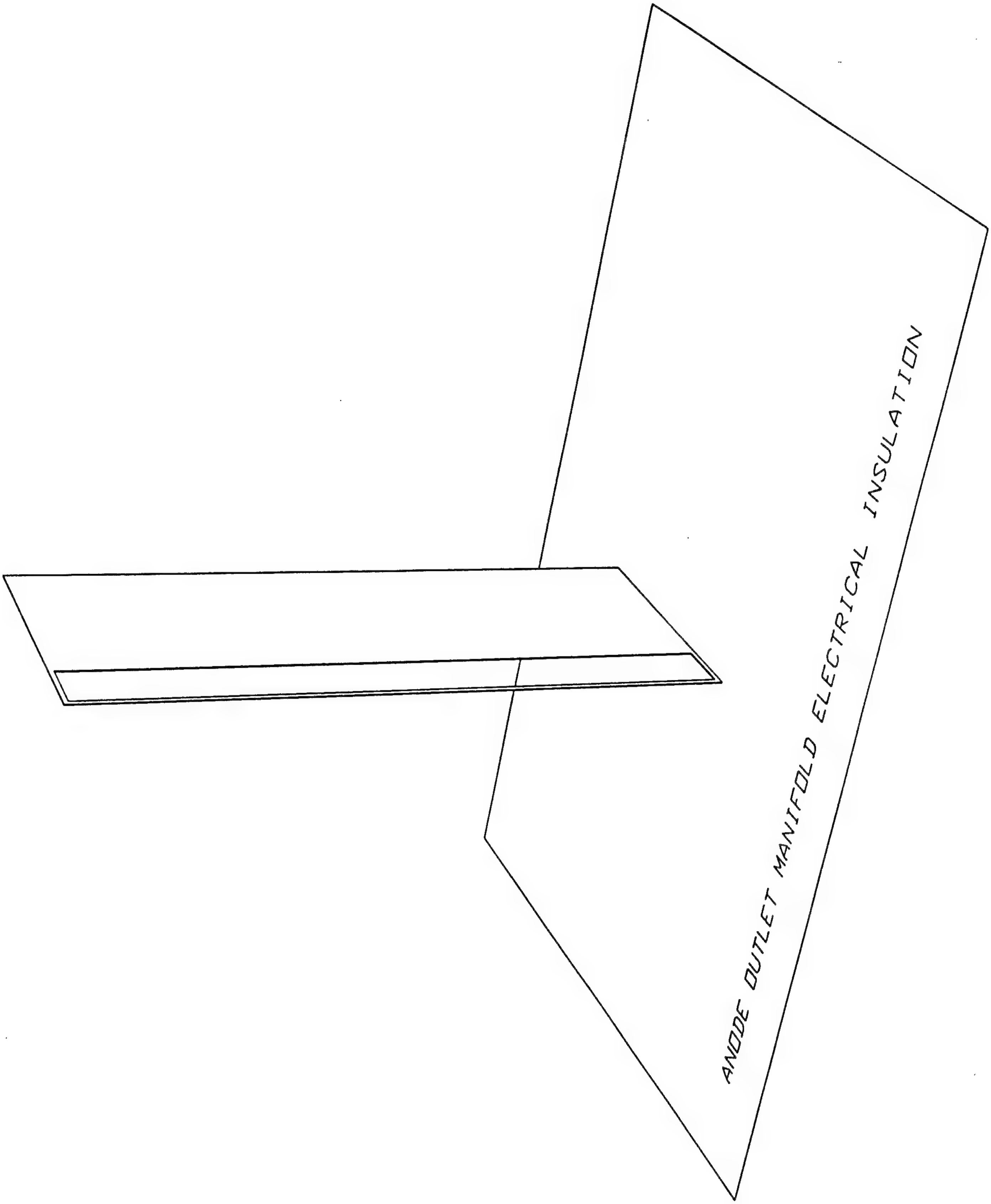

Dia= 1-1/4"
6'-9 5/16"
STACK ASSEMBLY ROD (4 PLACES)

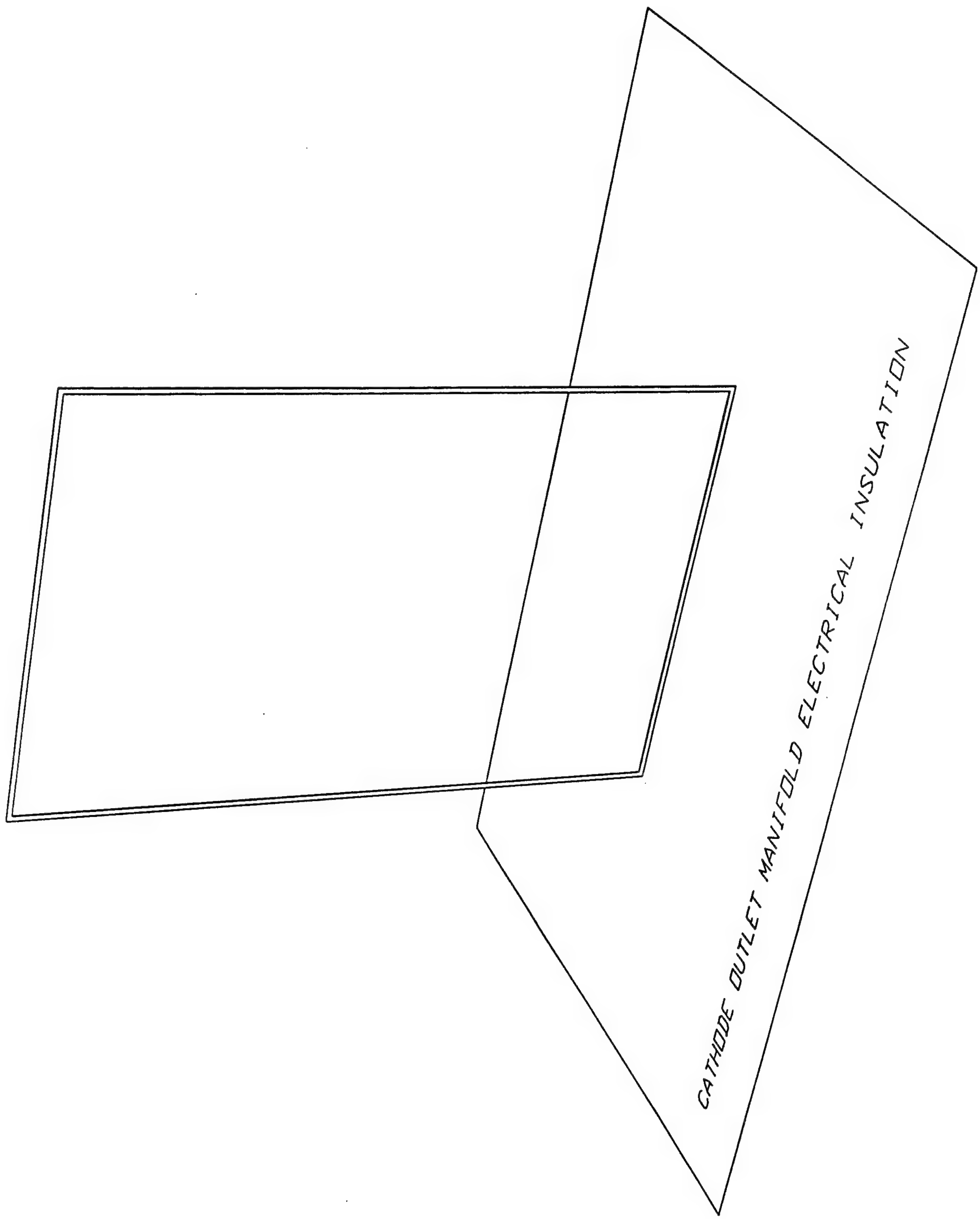

TOP THERMAL INSULATION FOR STACK

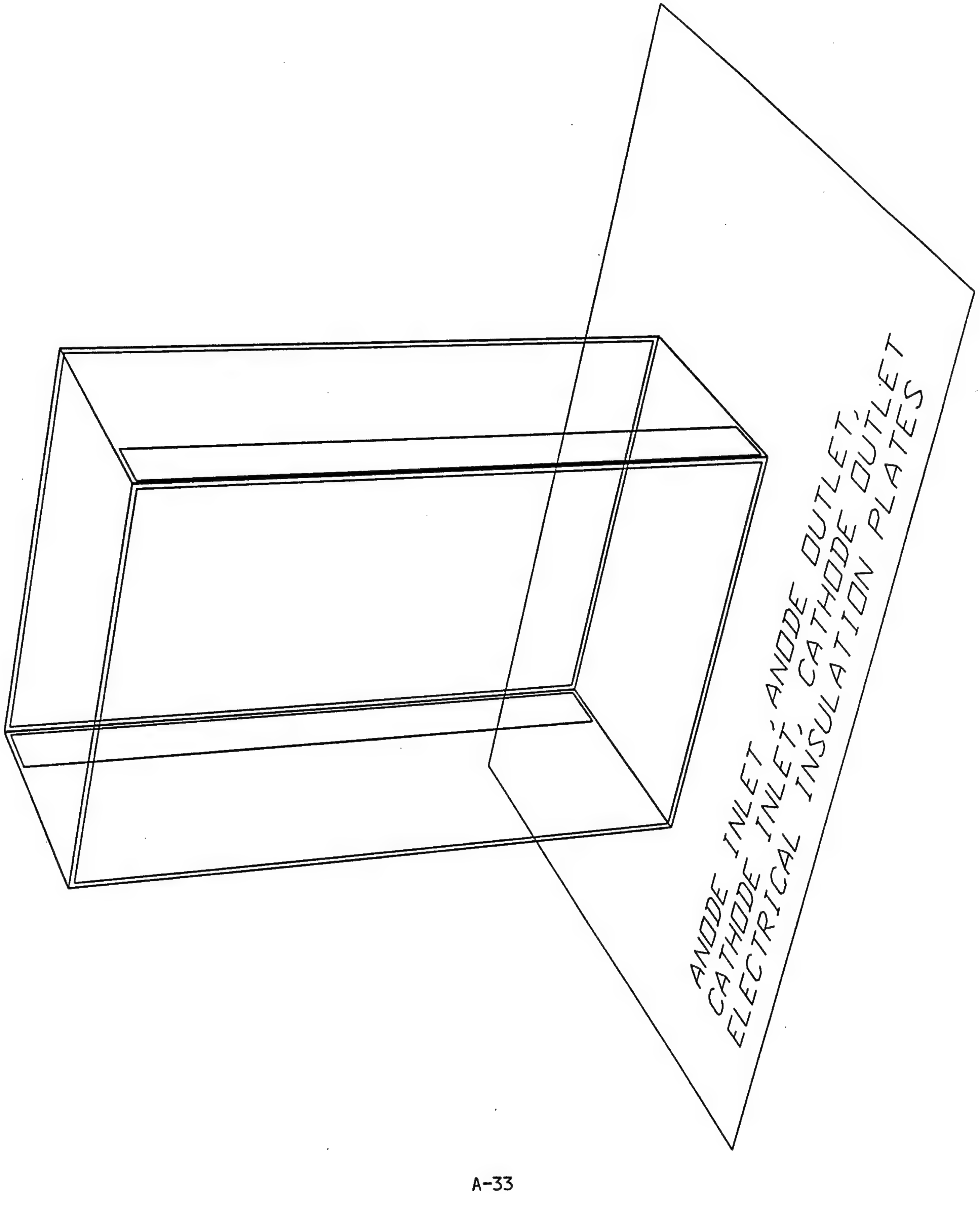

STACK

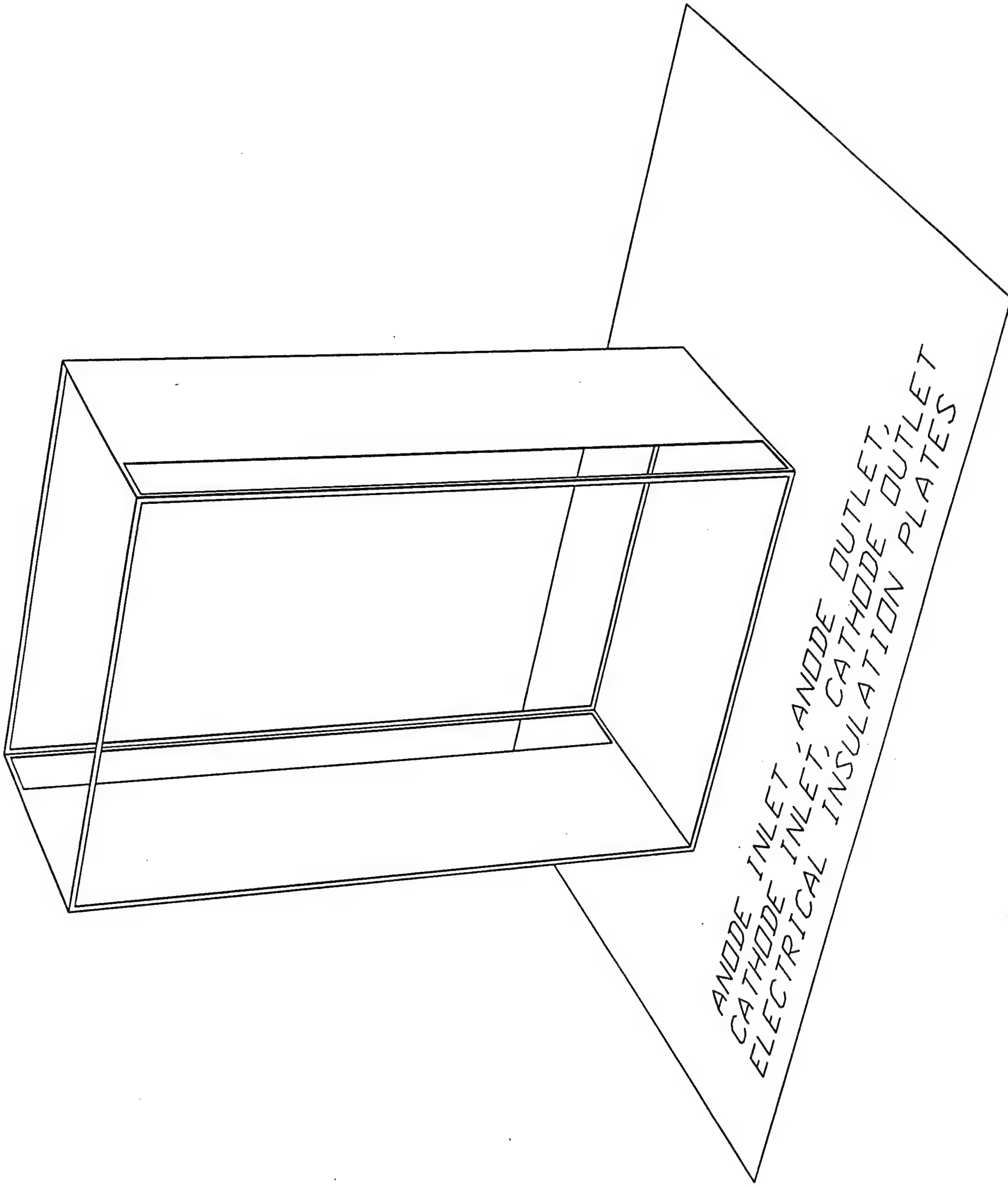

ANODE INLET MANIFOLD ELECTRICAL INSULATION

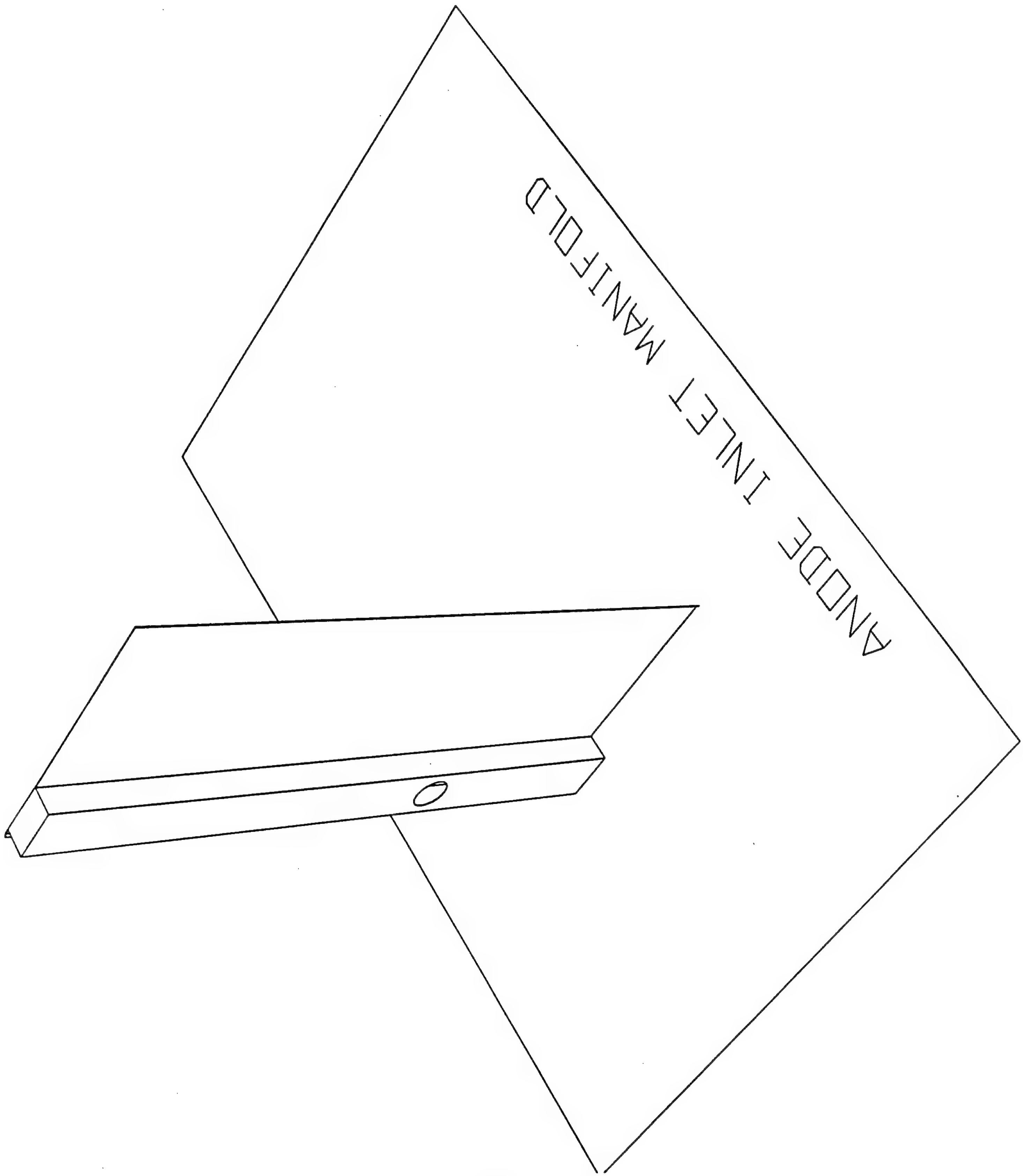

CATHODE INLET MANIFOLD ELECTRICAL INSULATION

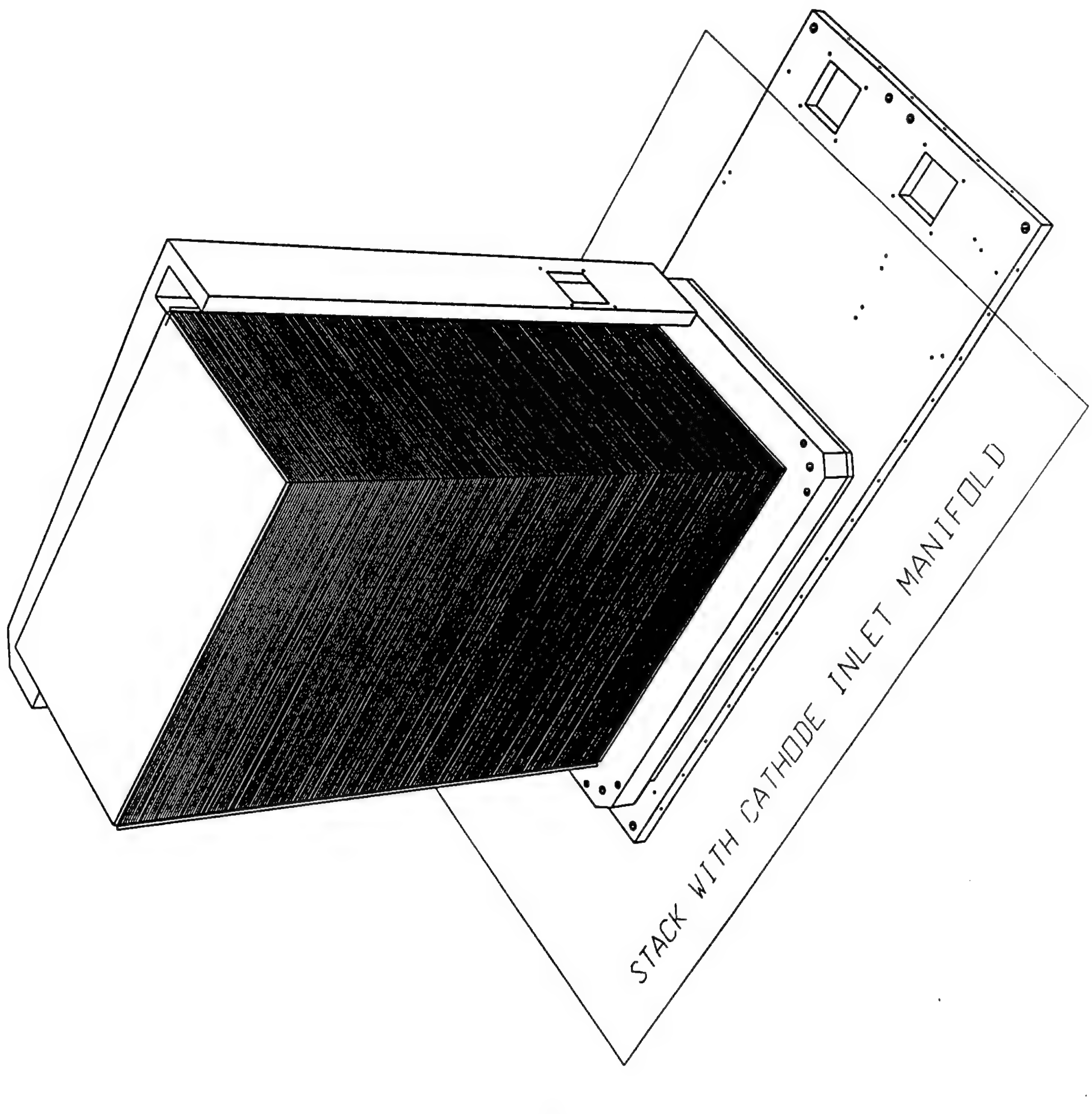

ANODE OUTLET MANIFOLD ELECTRICAL INSULATION

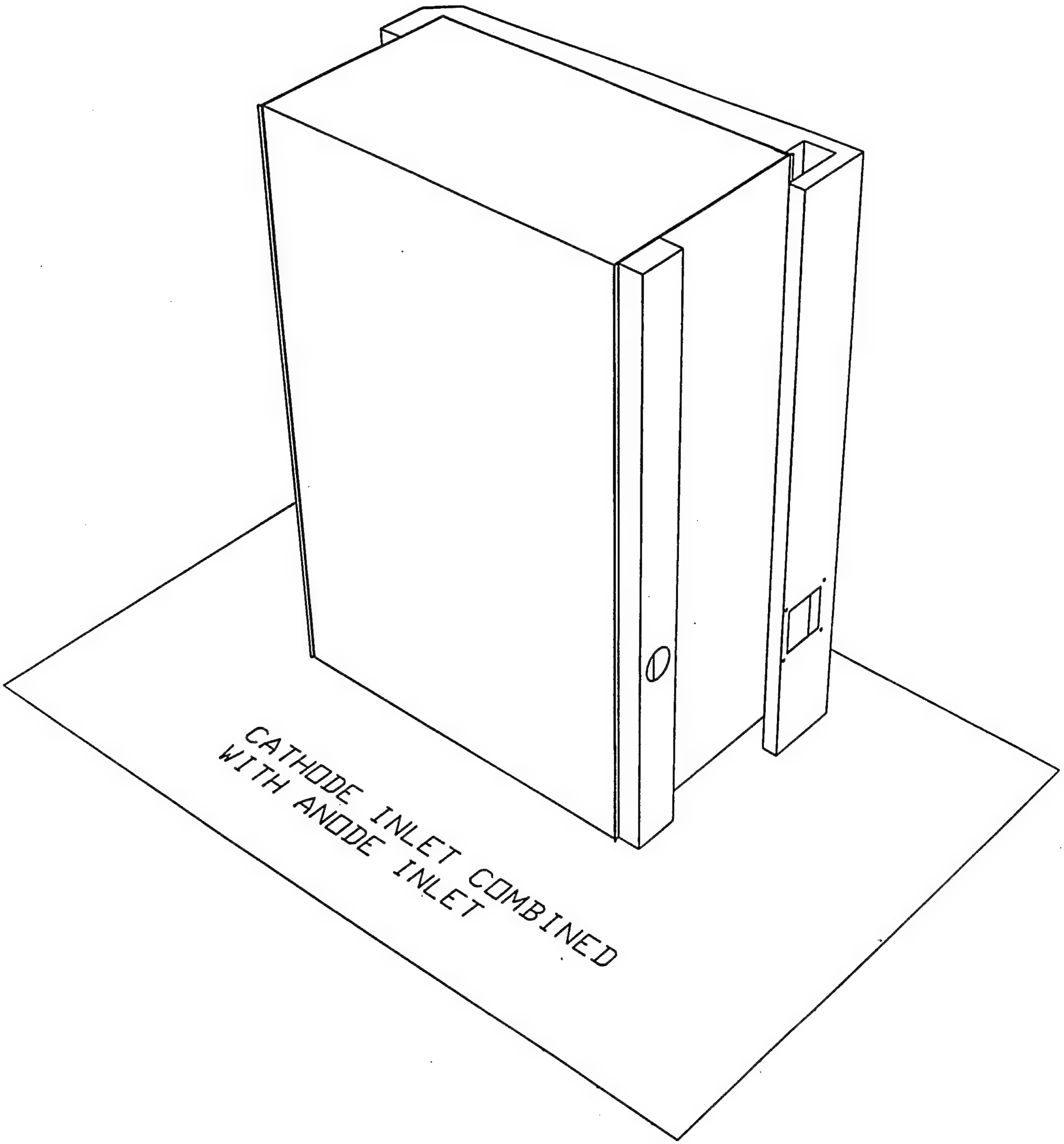

CATHODE OUTLET MANIFOLD ELECTRICAL INSULATION

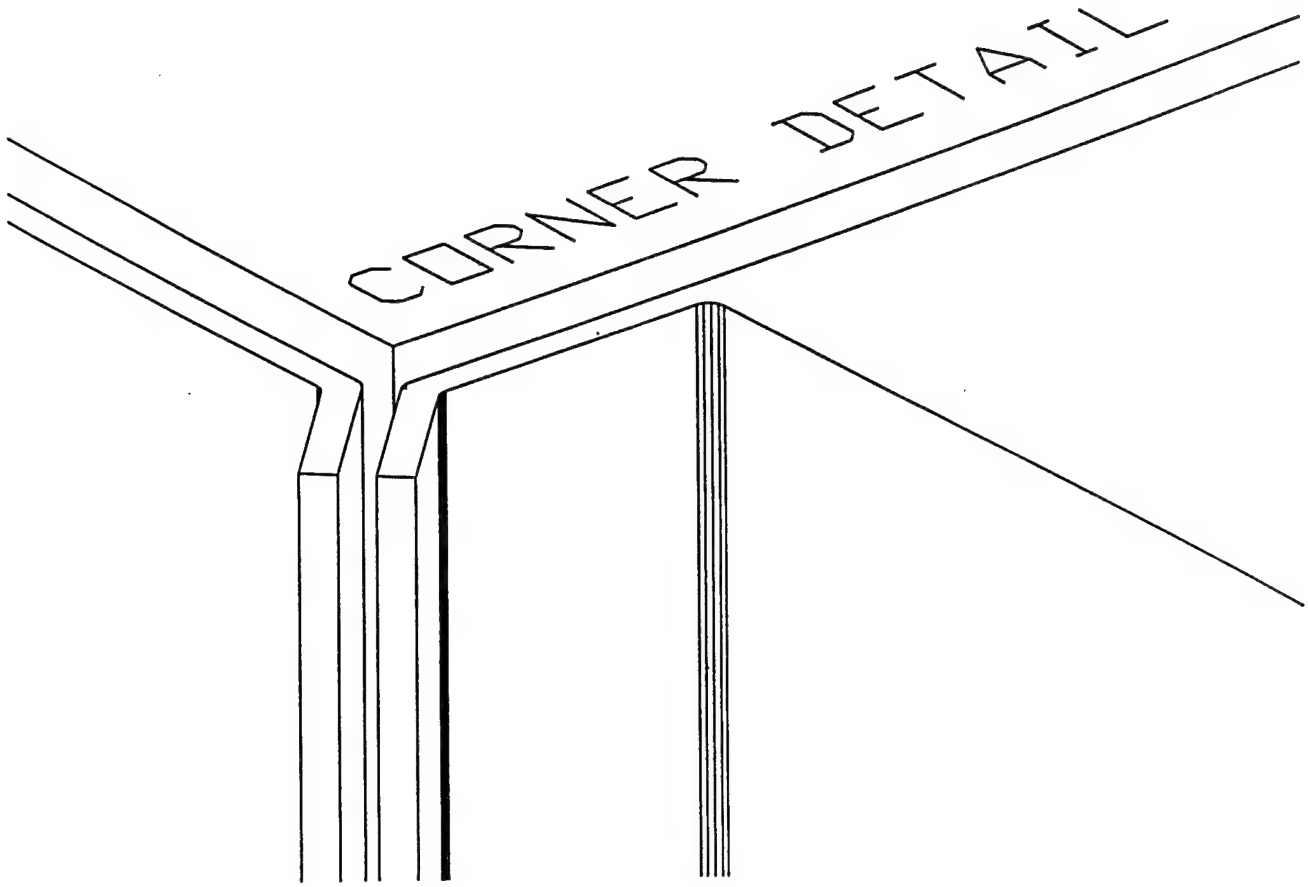

ANODE INLET; ANODE OUTLET;
CATHODE INLET; CATHODE OUTLET
ELECTRICAL INSULATION PLATES

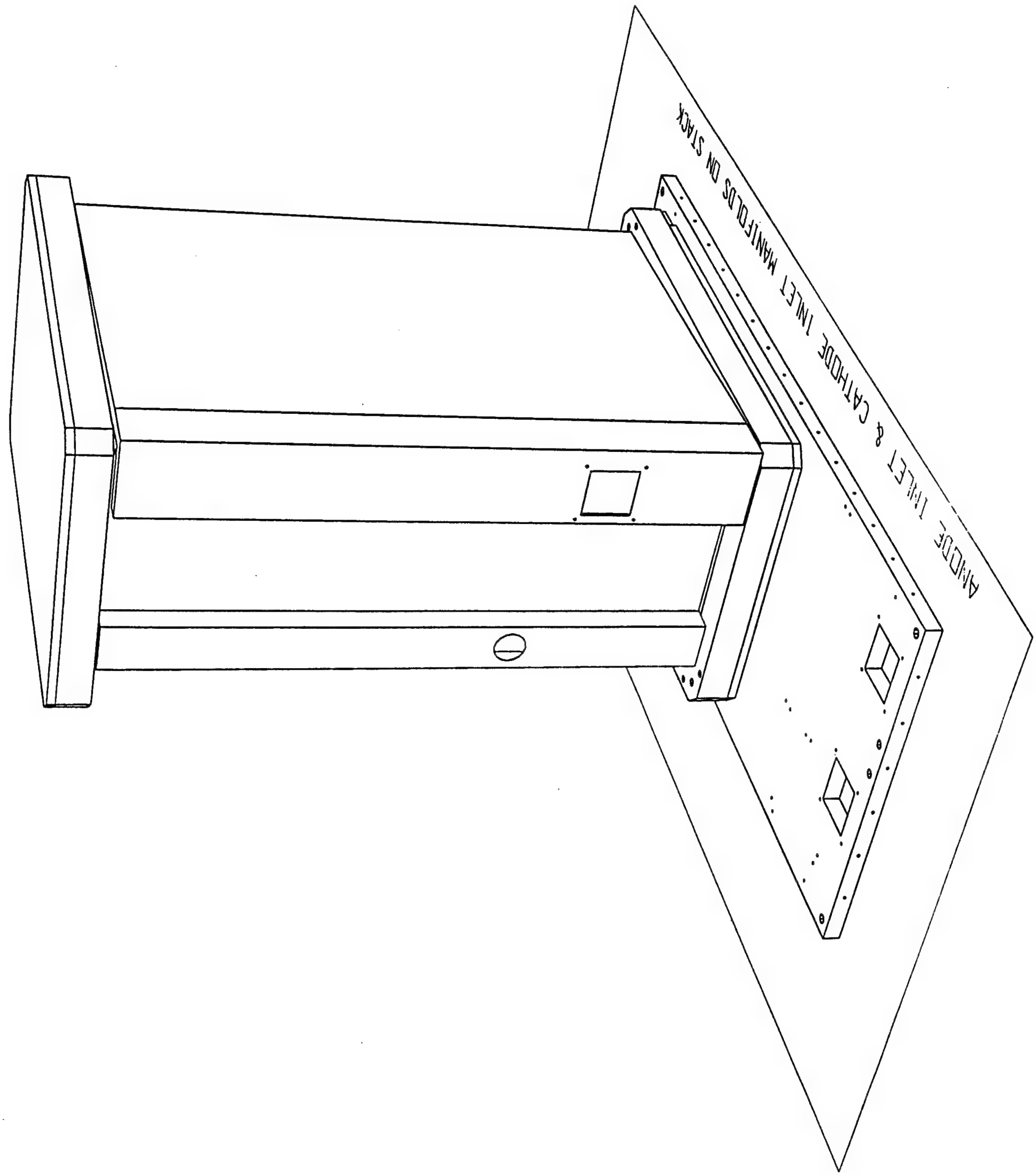

ANODE INLET; ANODE OUTLET;
CATHODE INLET; CATHODE OUTLET
ELECTRICAL INSULATION PLATES

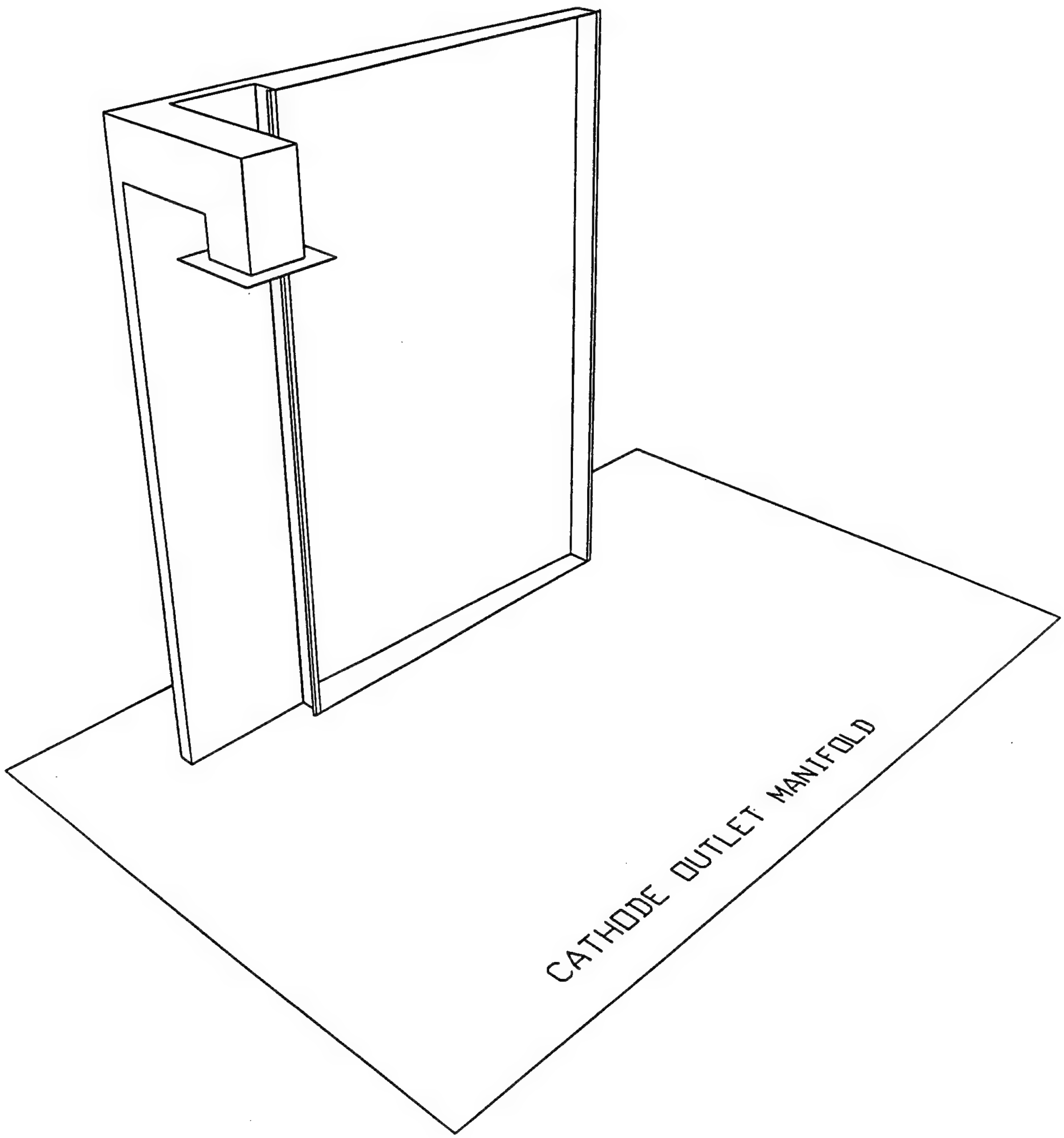

ANODE INLET MANIFOLD

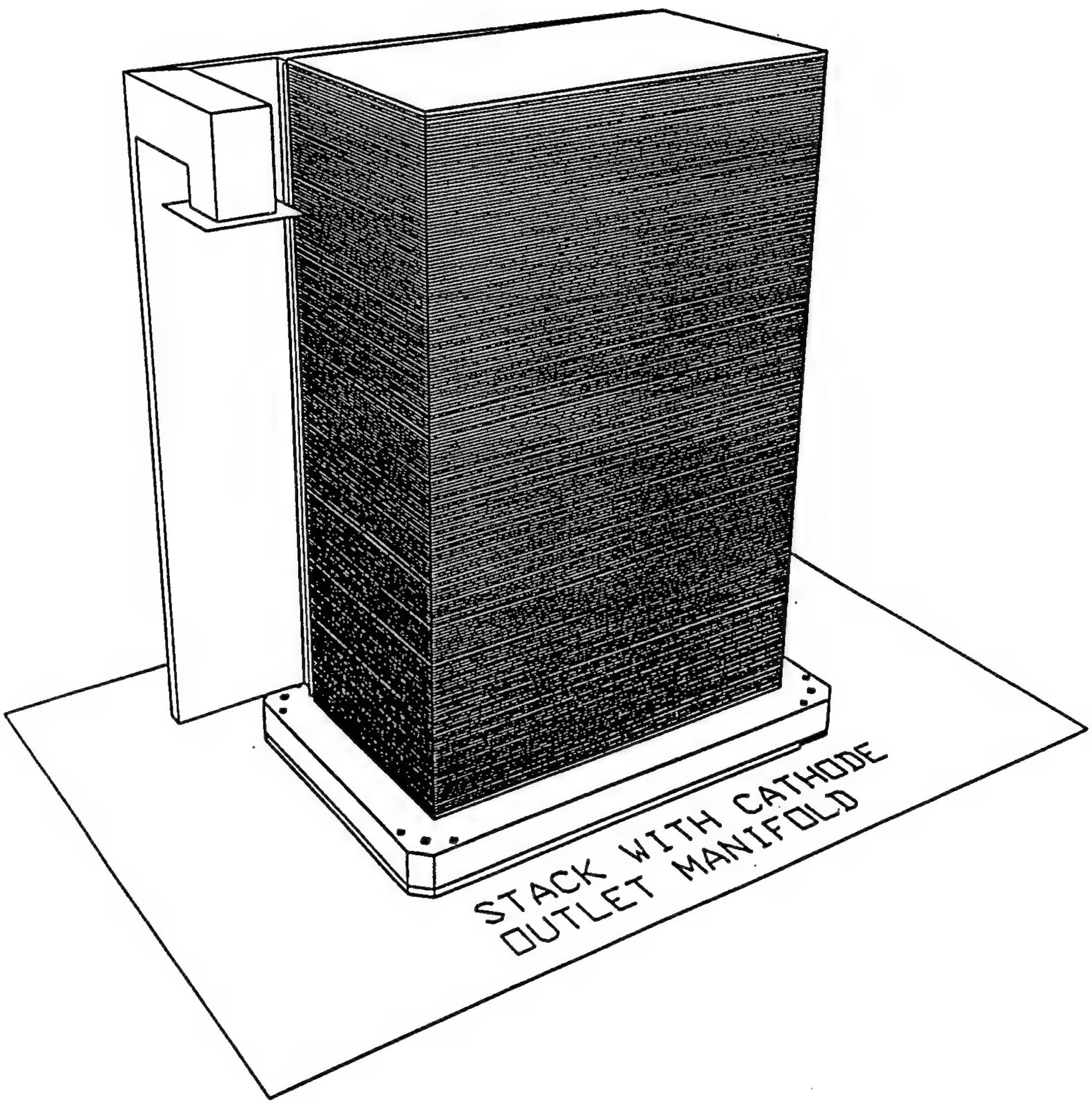

STACK WITH CATHODE INLET MANIFOLD

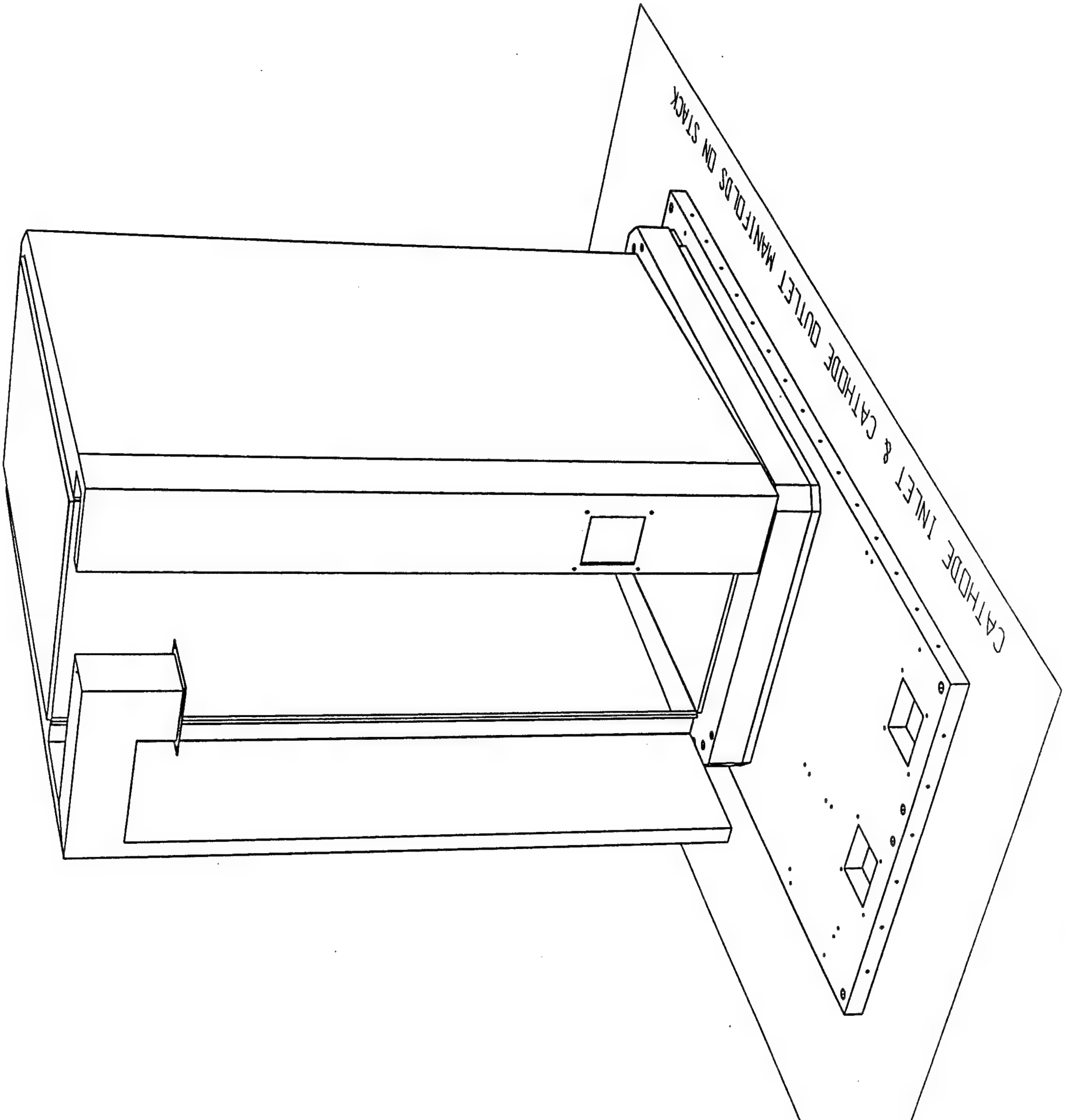

CATHODE INLET COMBINED
WITH ANODE INLET

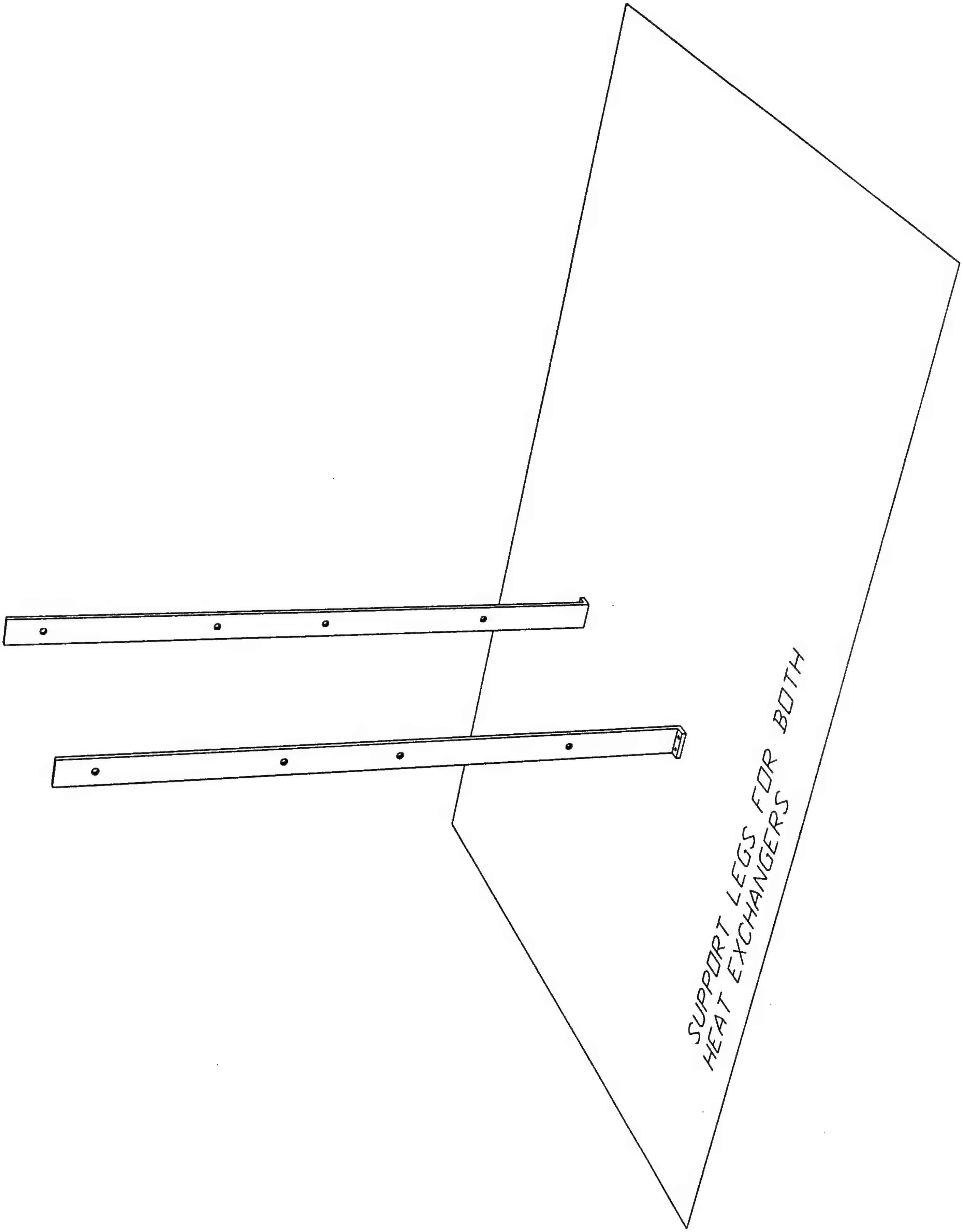

CORNER DETAIL

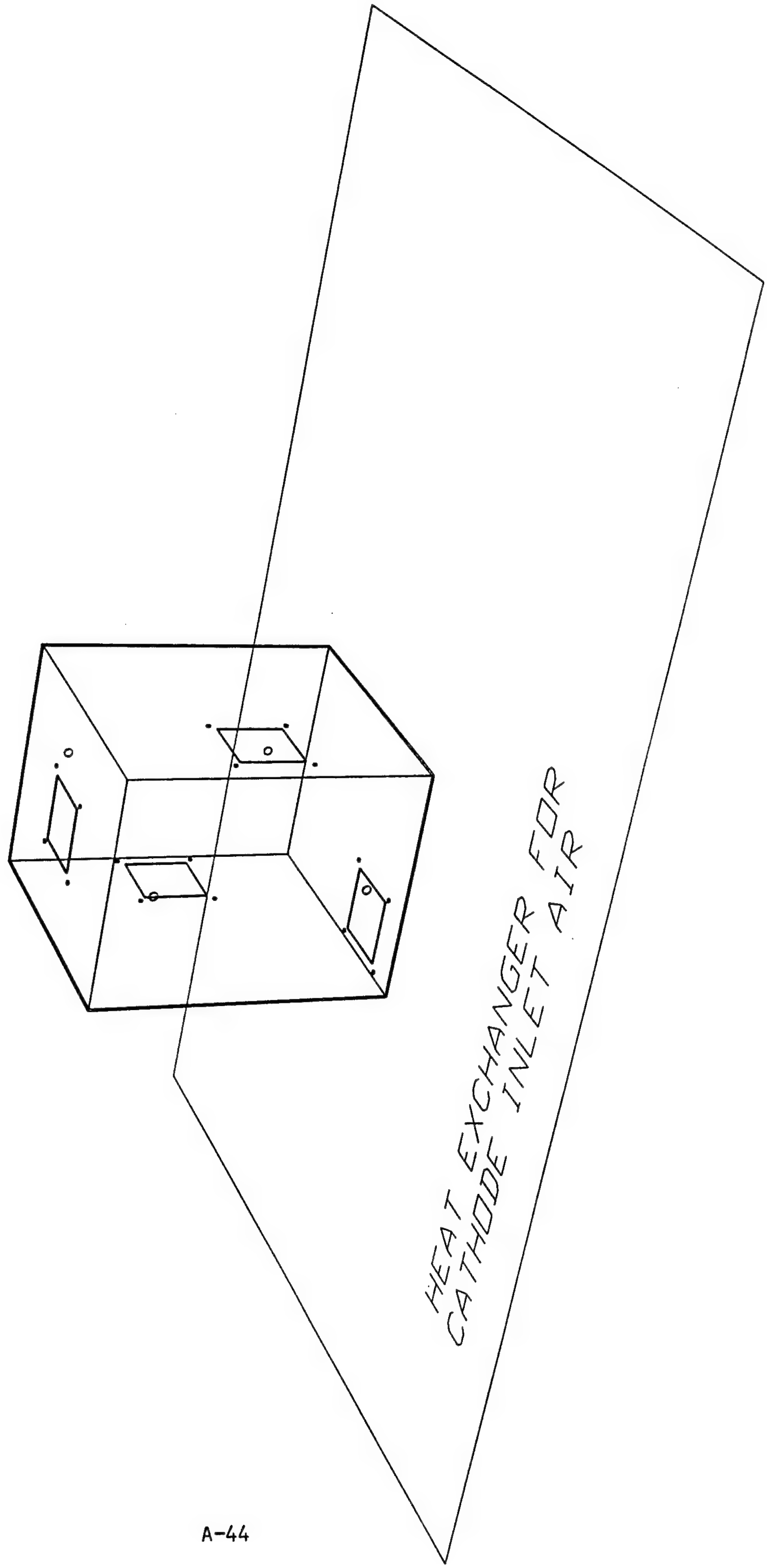

ANODE INLET & CATHODE INLET MANIFOLDS ON STACK

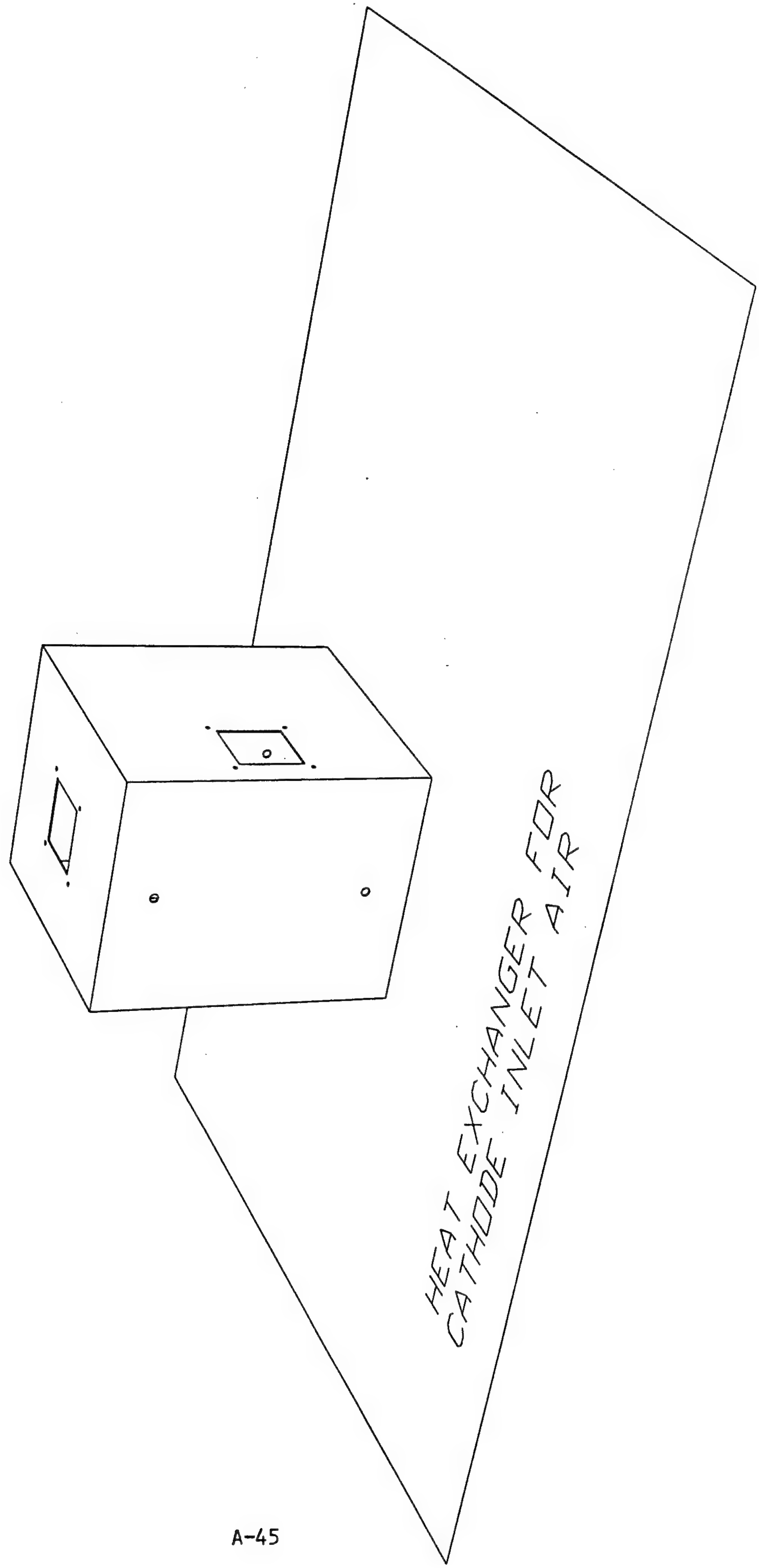

CATHODE OUTLET MANIFOLD

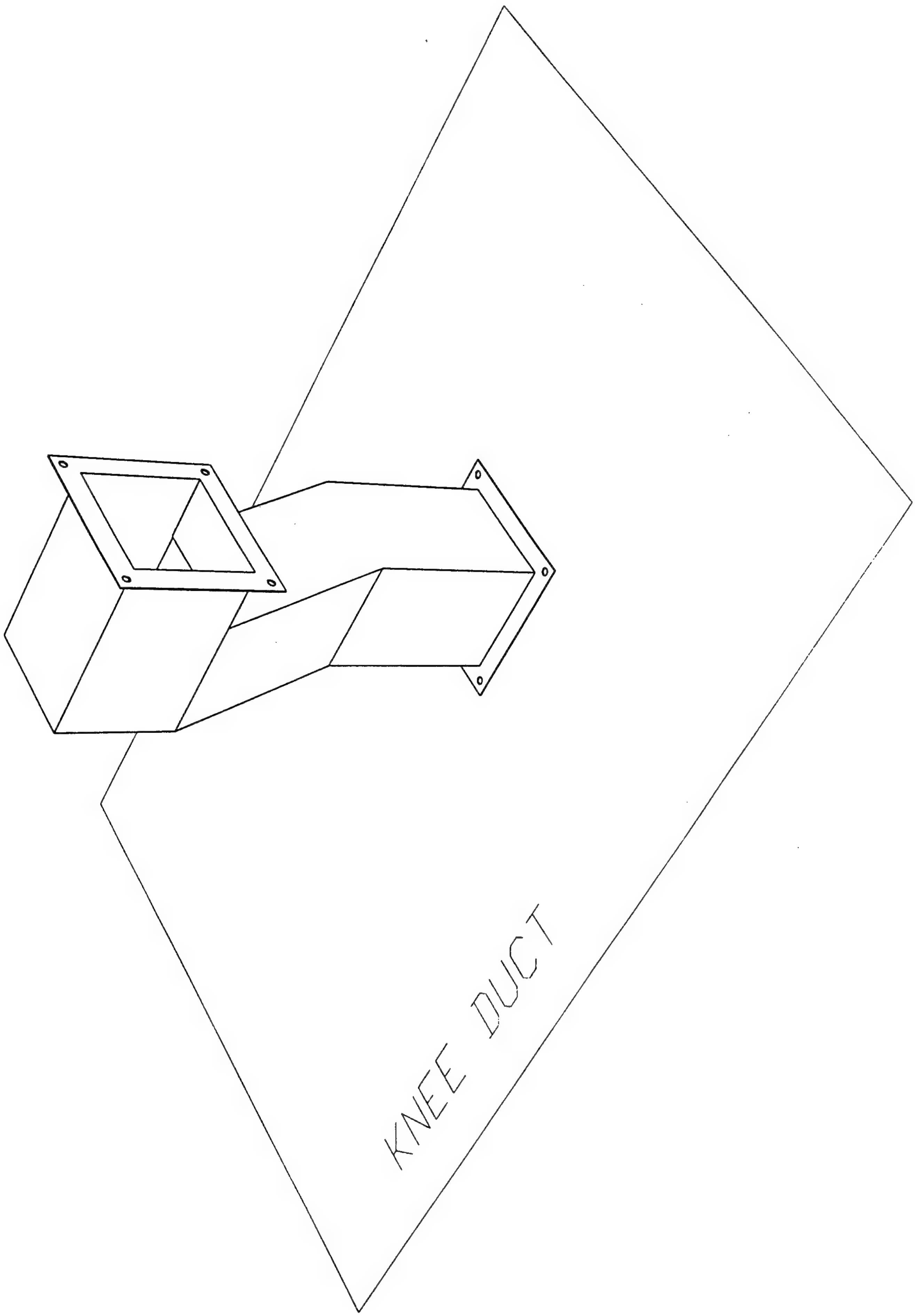

STACK WITH CATHODE
OUTLET MANIFOLD

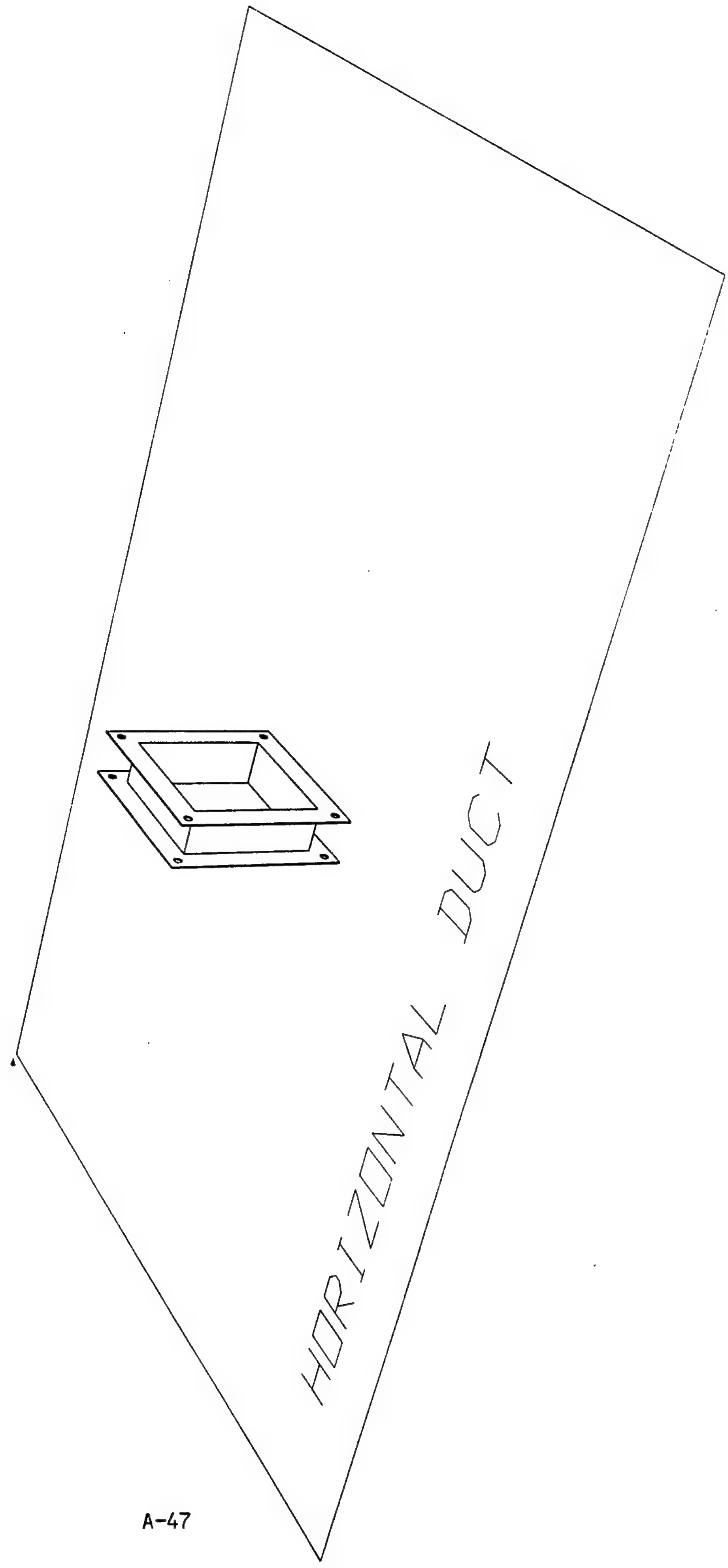

CATHODE INLET & CATHODE OUTLET MANIFOLDS ON STACK

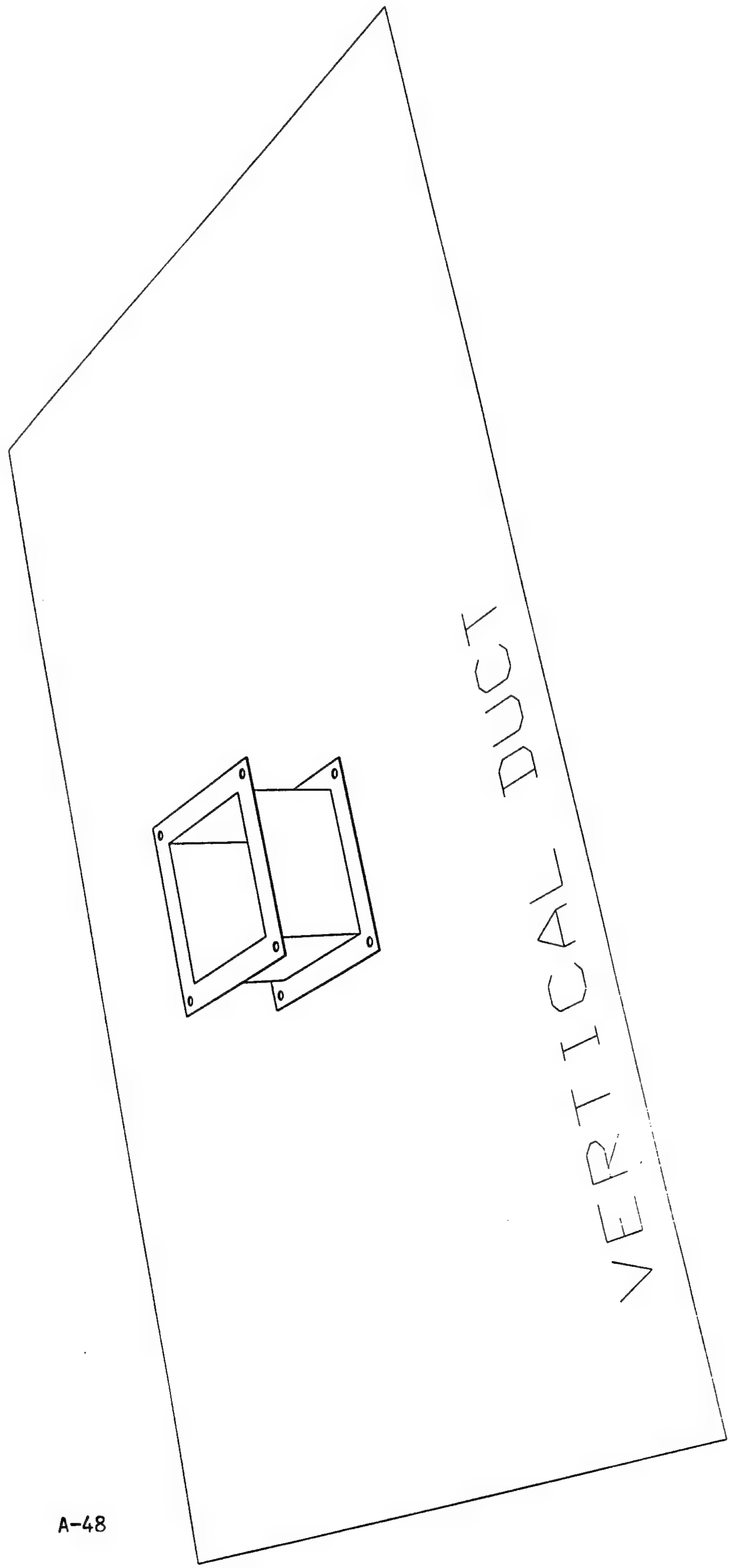

SUPPORT LEGS FOR BOTH
HEAT EXCHANGERS

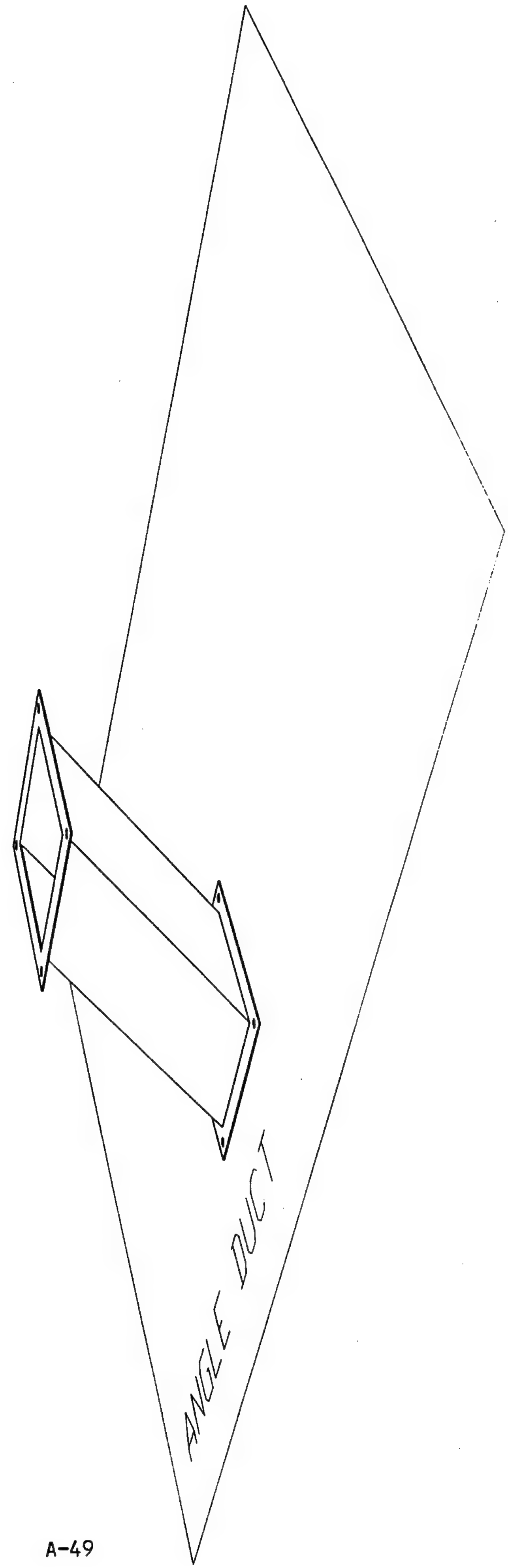

HEAT EXCHANGER FOR
CATHODE INLET AIR

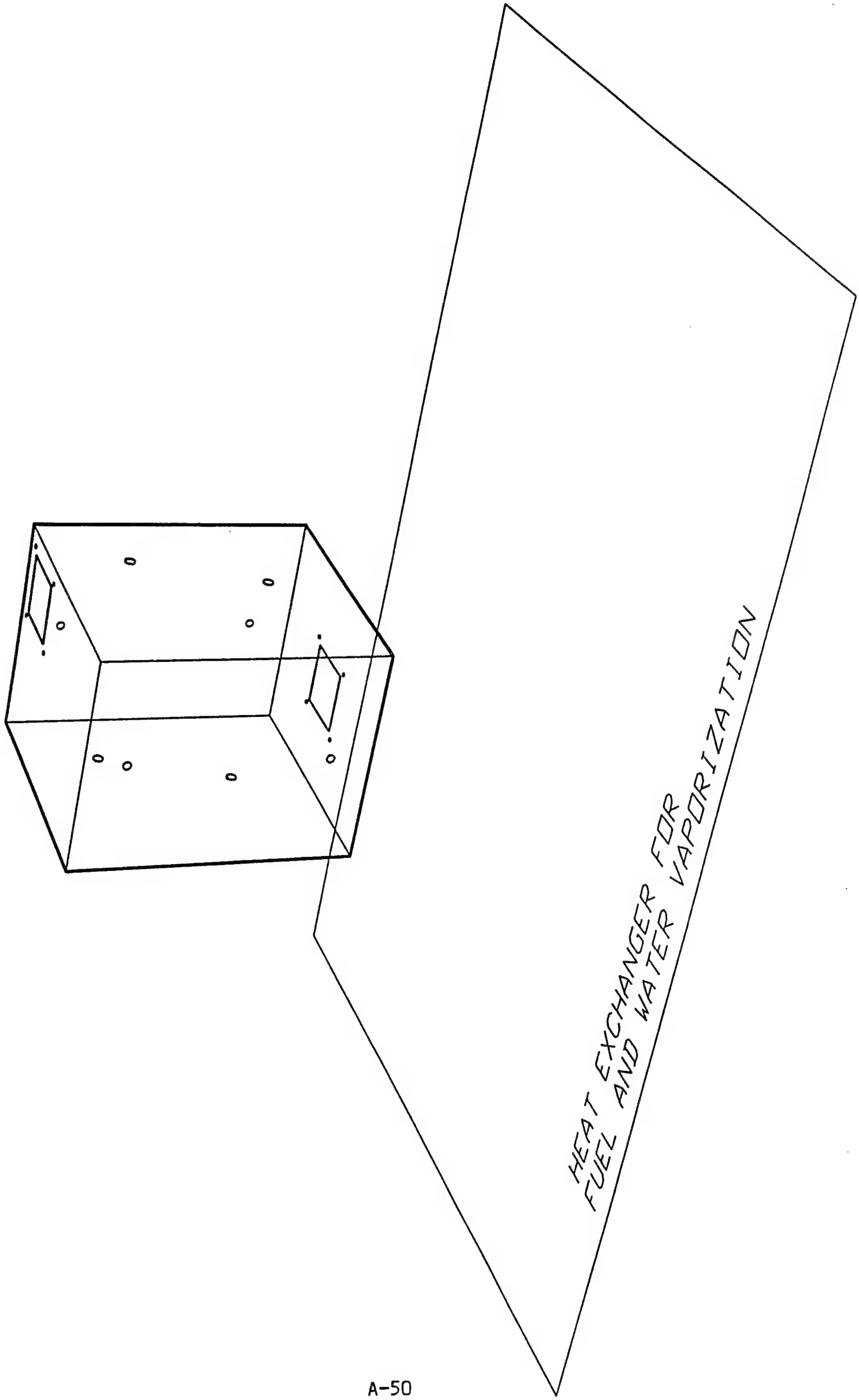

HEAT EXCHANGER FOR
CATHODE INLET AIR

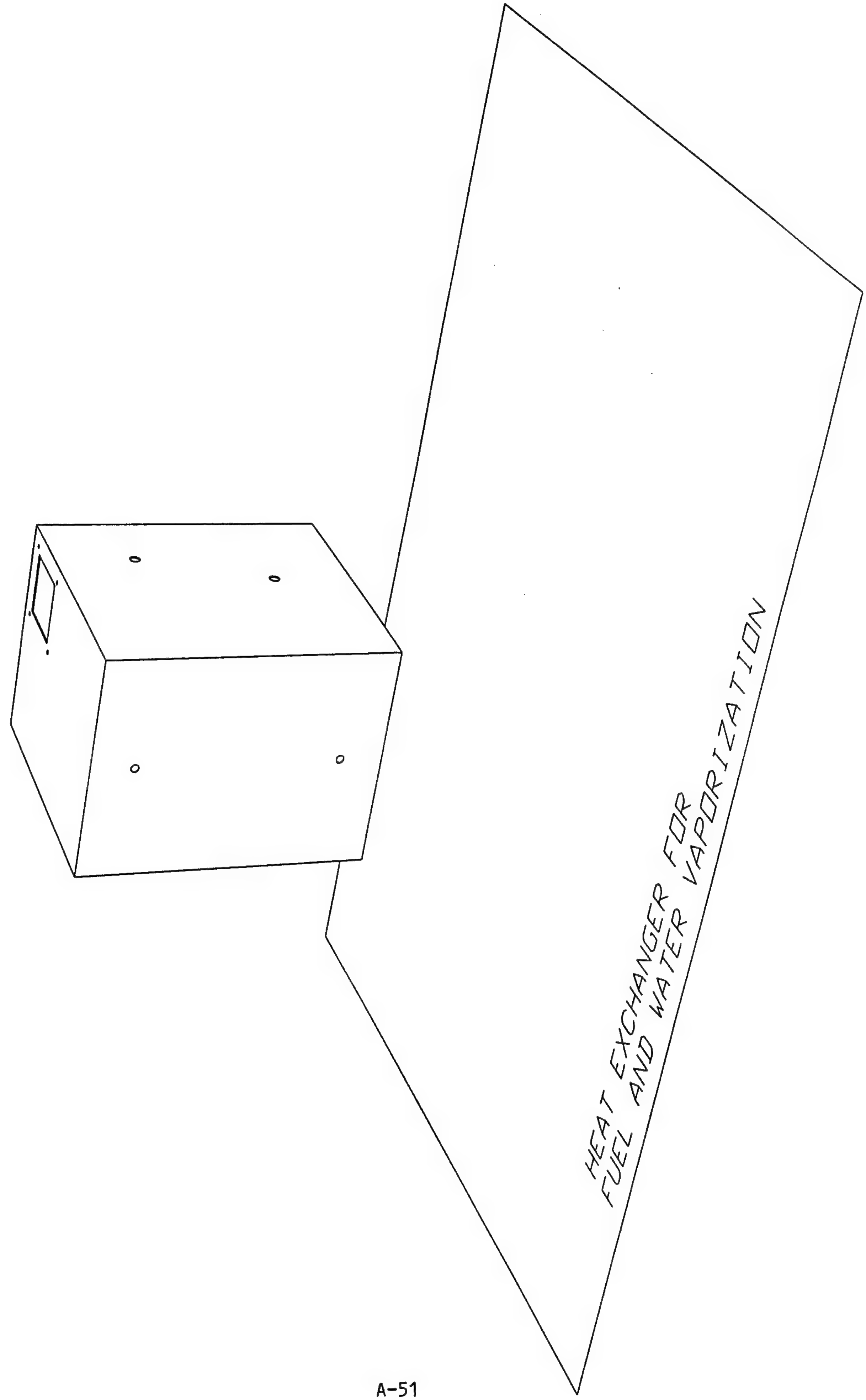

KNEE DUCT

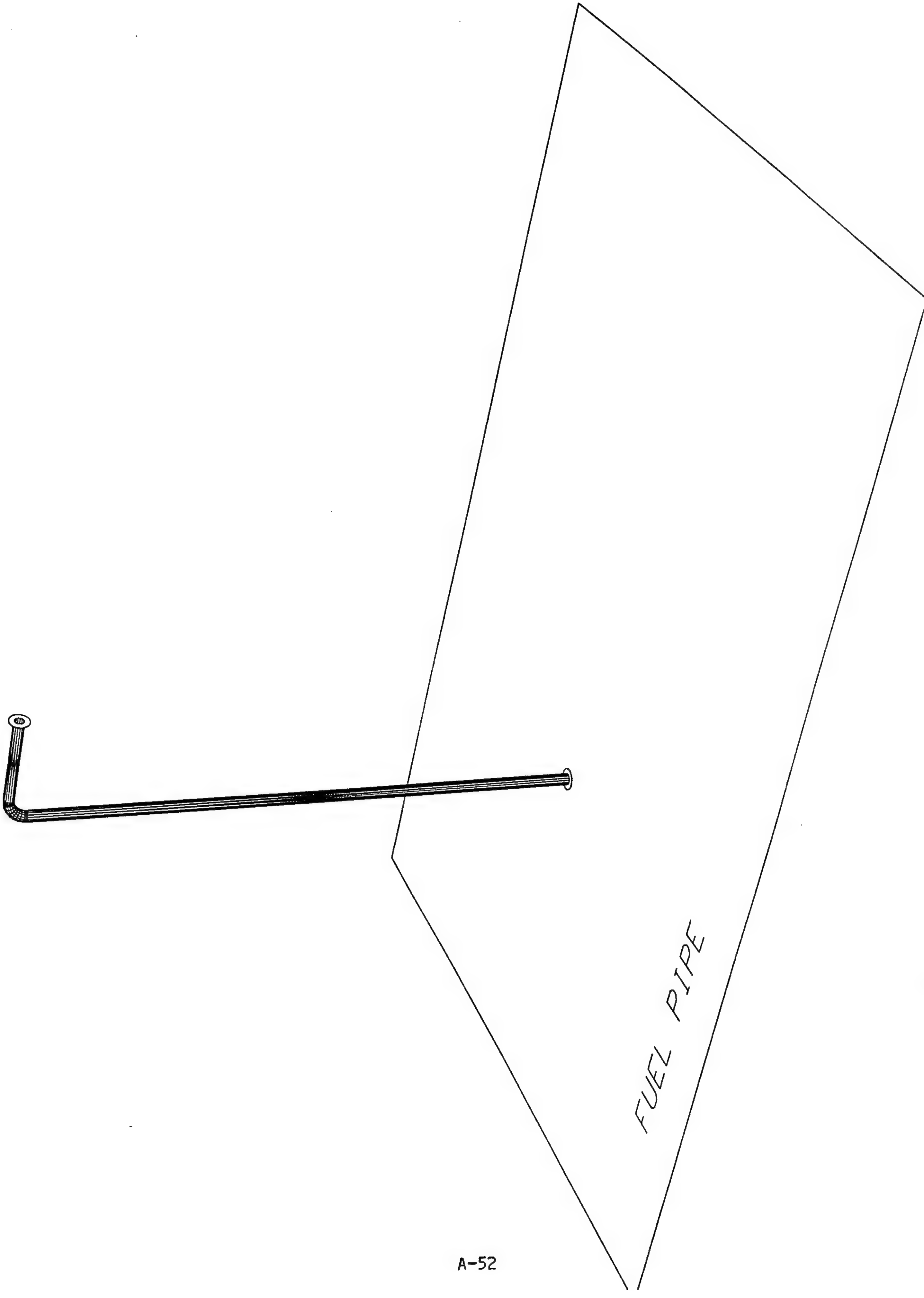

HORIZONTAL DUCT

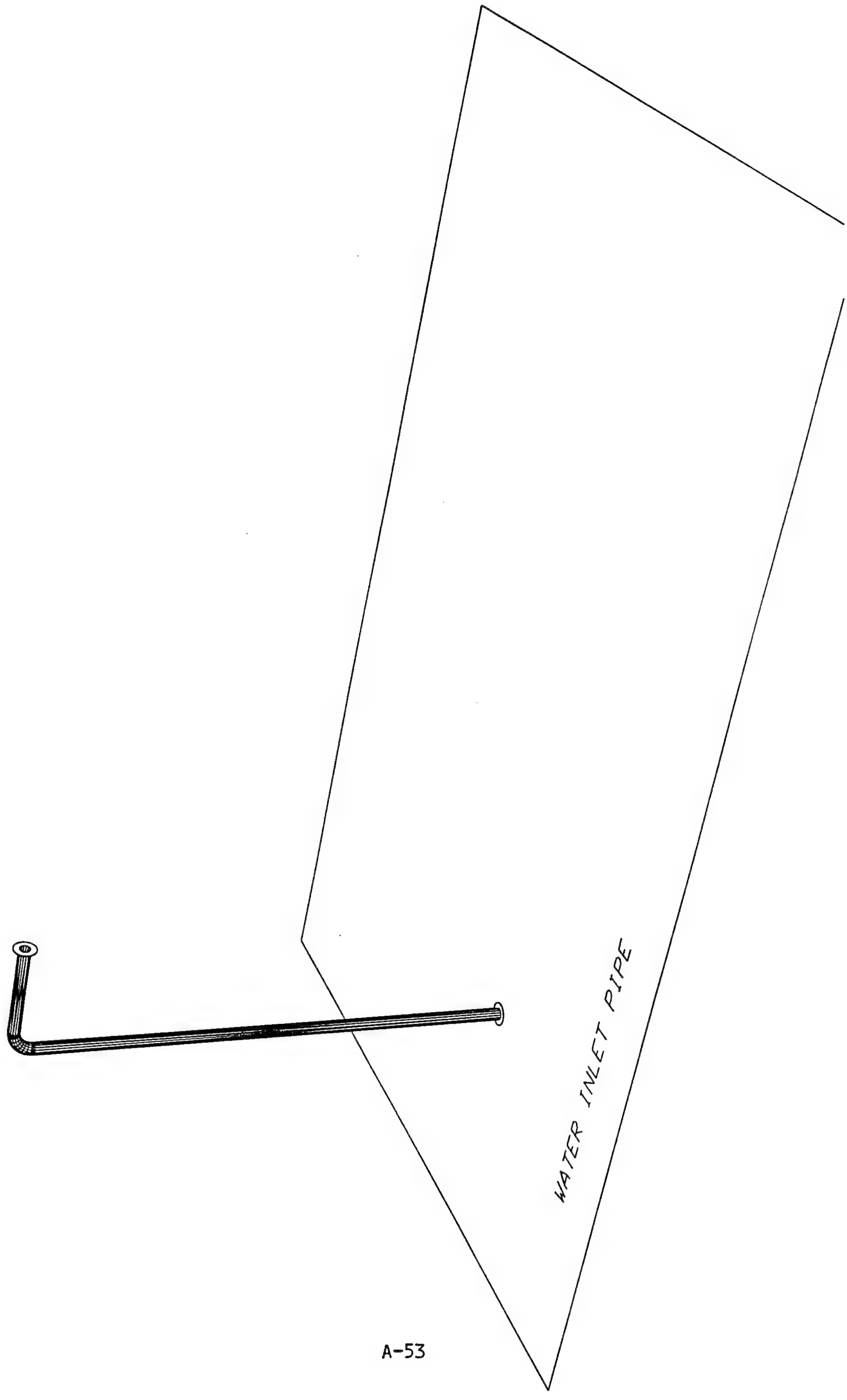

VERTICAL DUCT

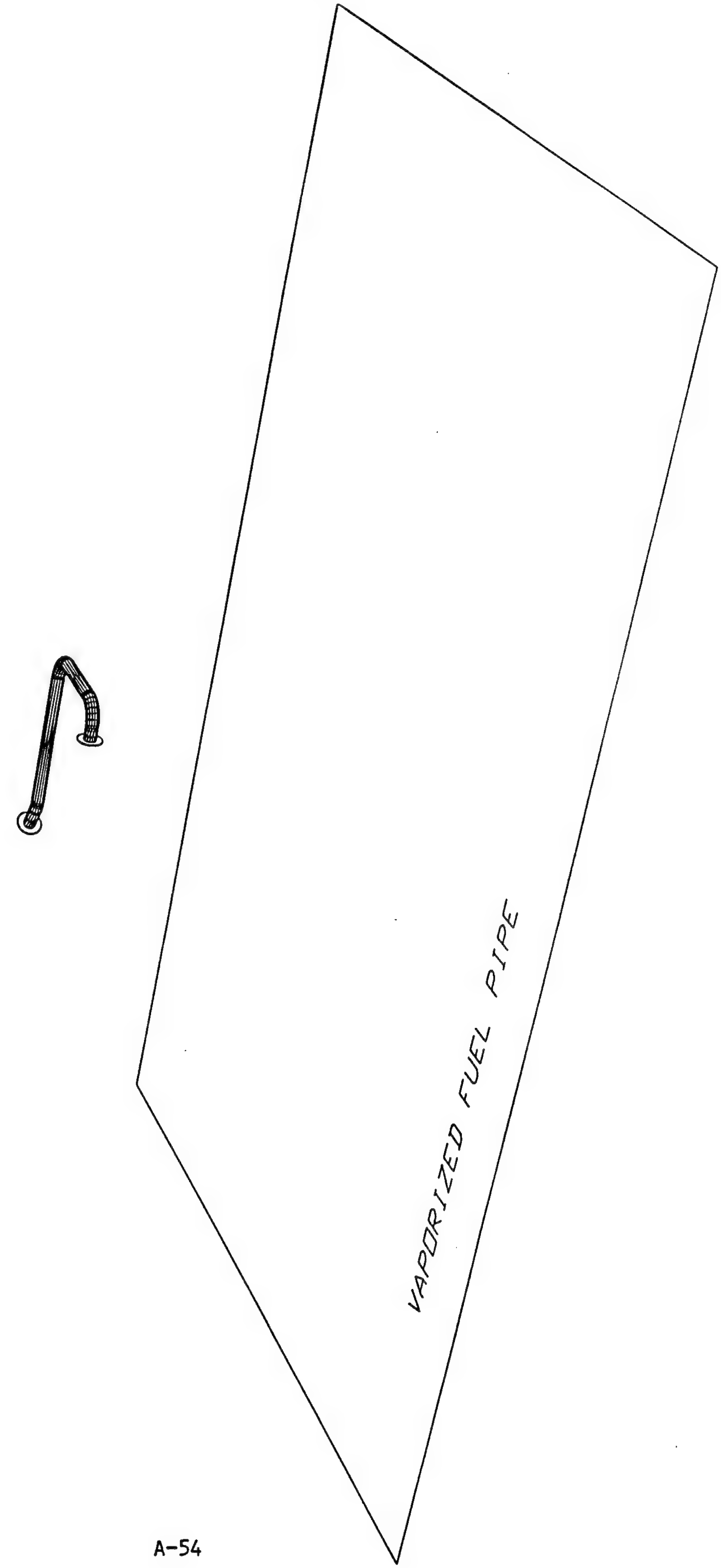

ANGLE DUCT

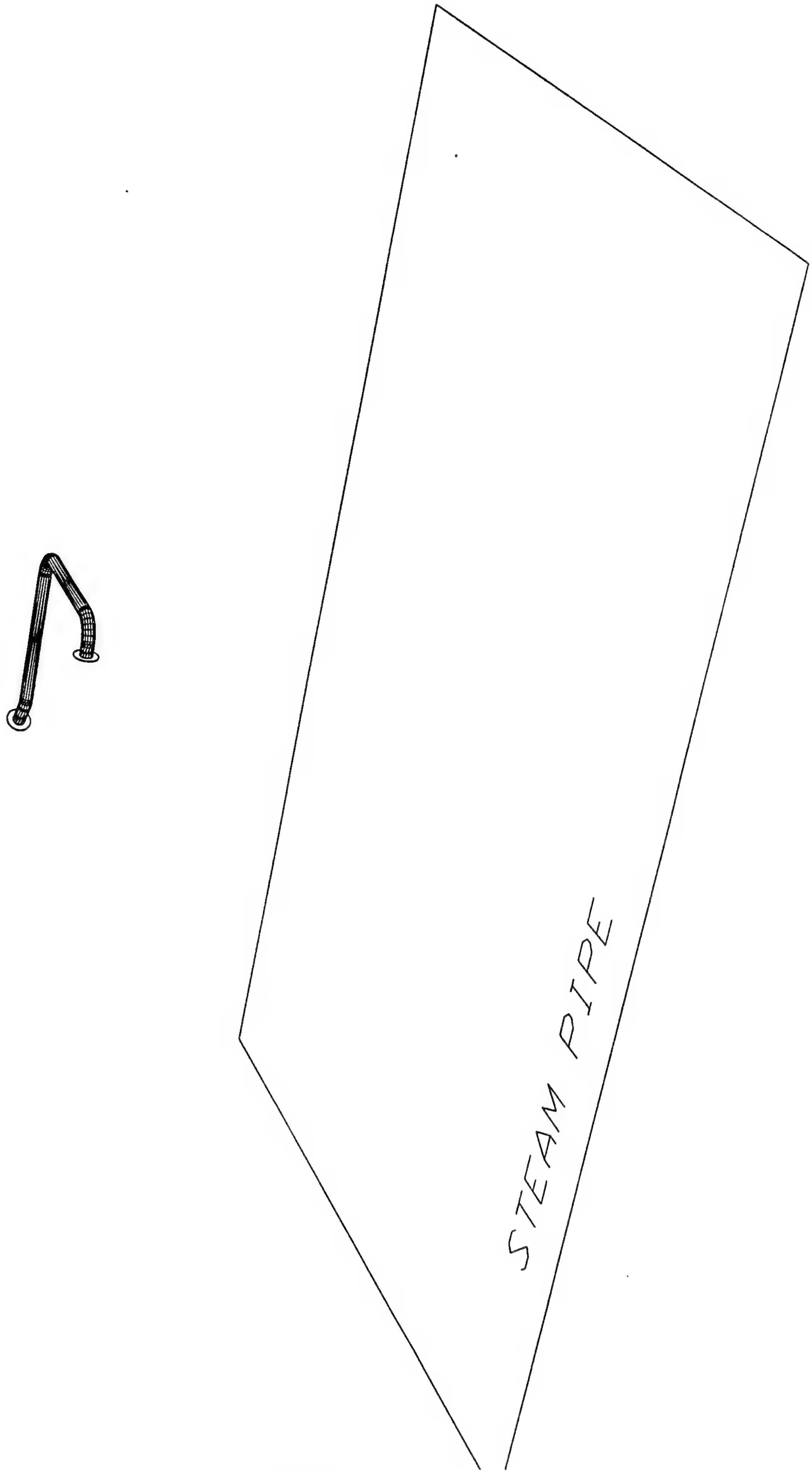

HEAT EXCHANGER FOR
FUEL AND WATER VAPORIZATION

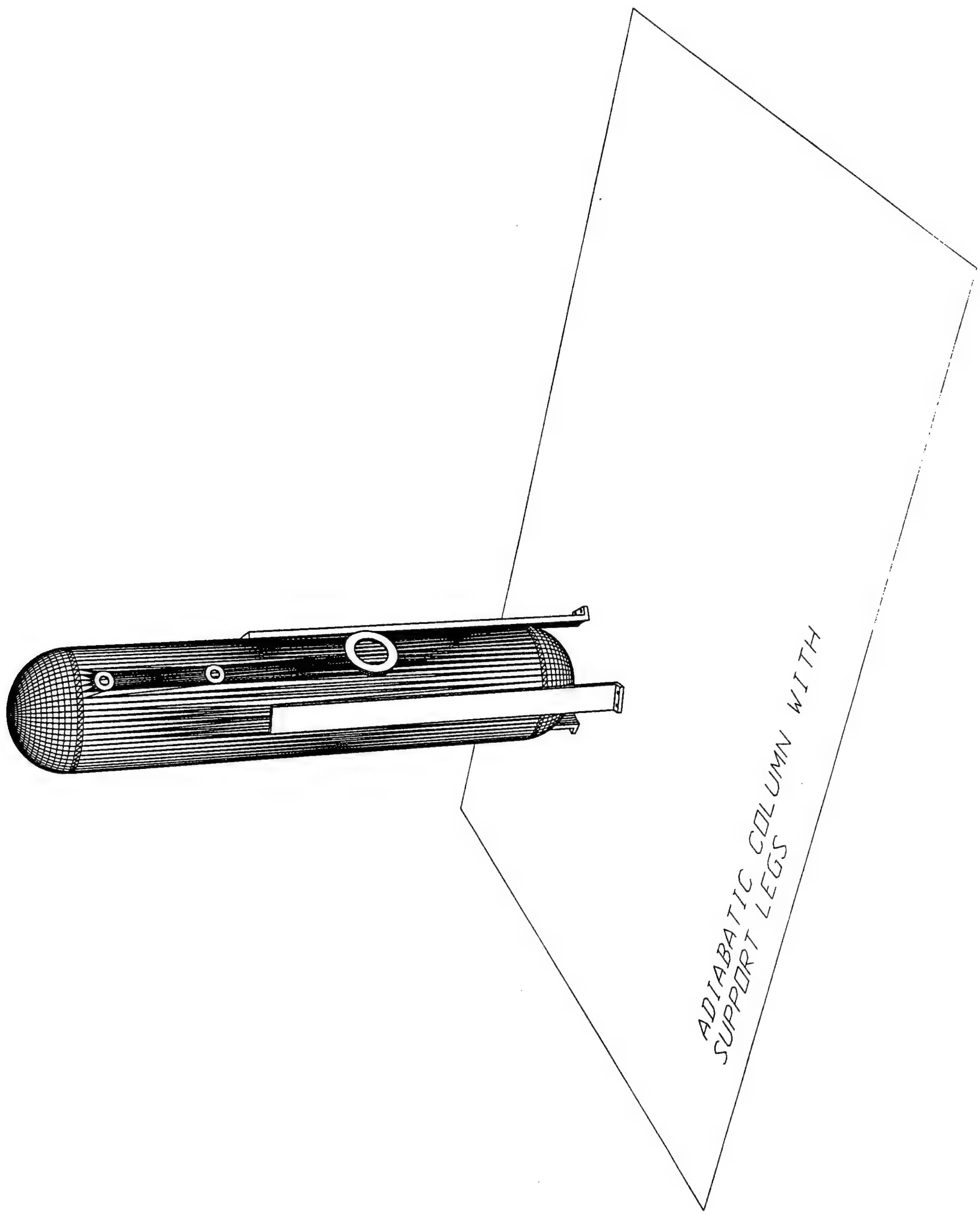

HEAT EXCHANGER FOR
FUEL AND WATER VAPORIZATION

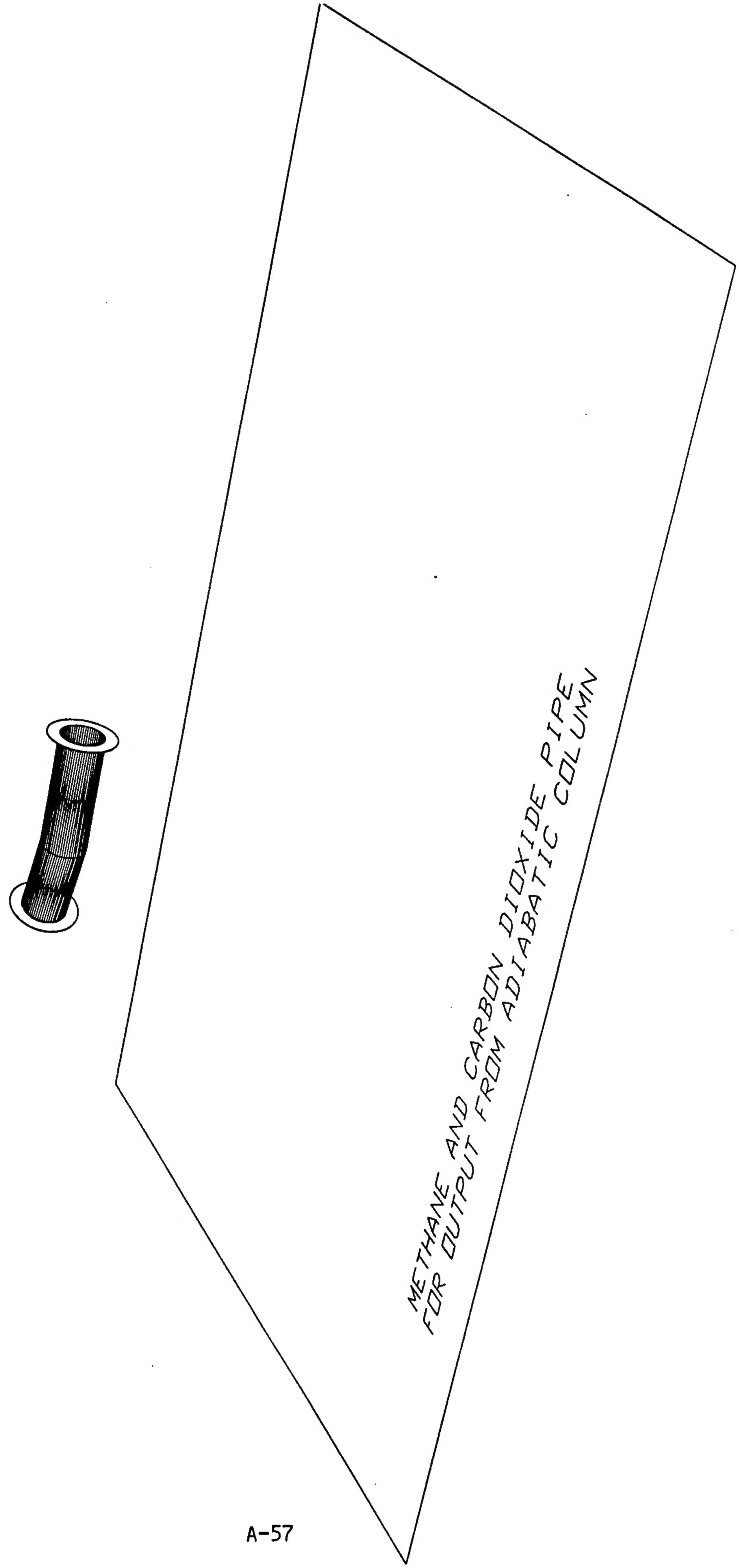

FUEL PIPE

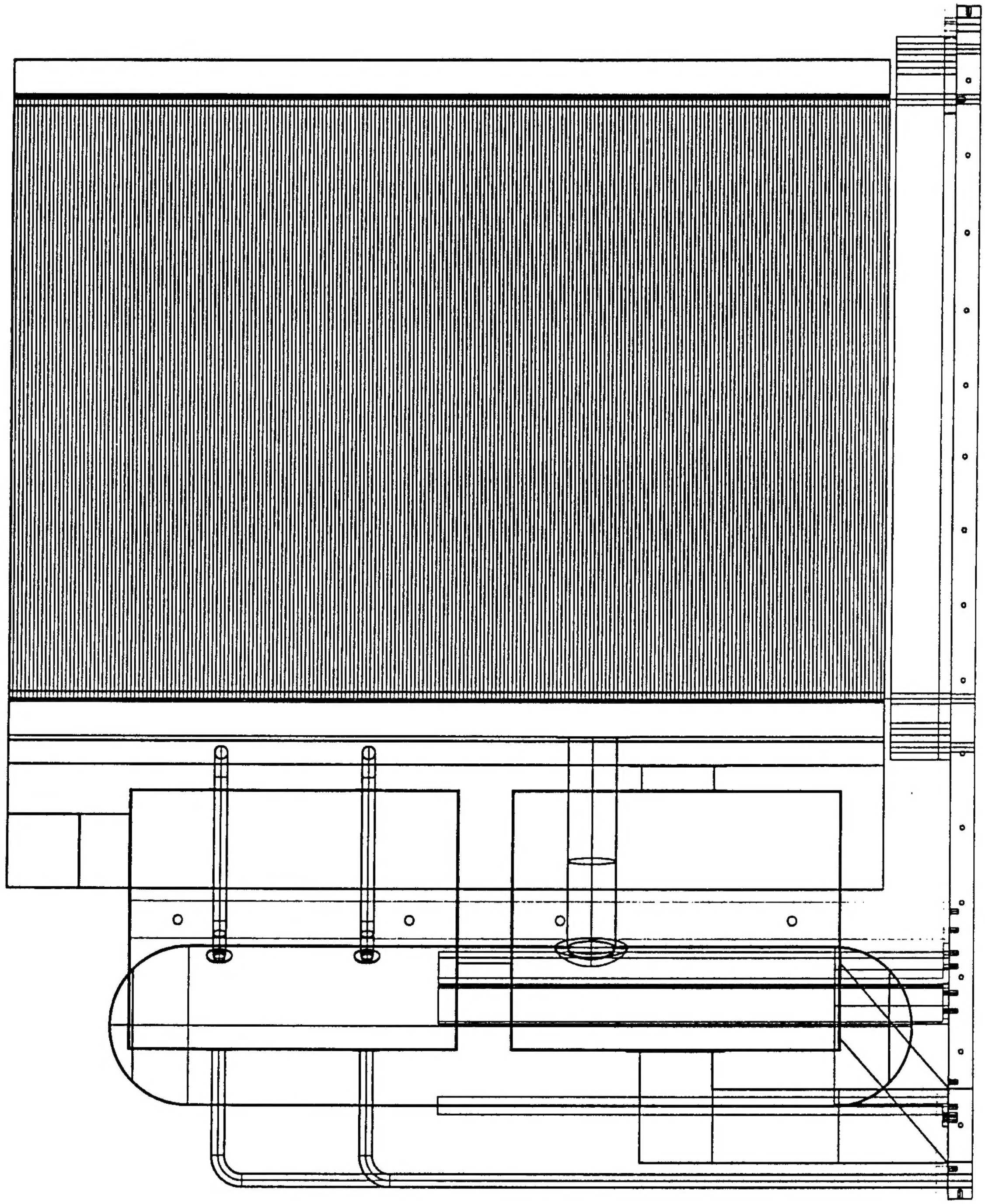

WATER INLET PIPE

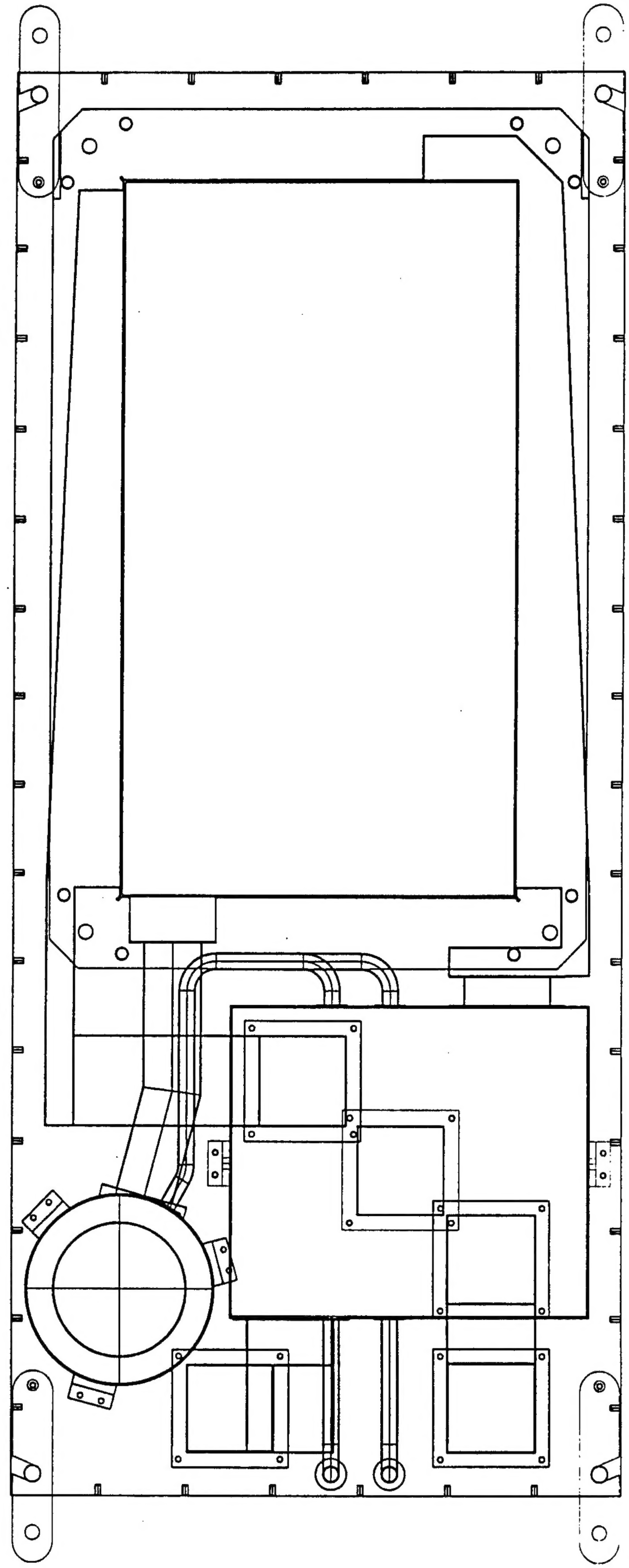

VAPORIZED FUEL PIPE

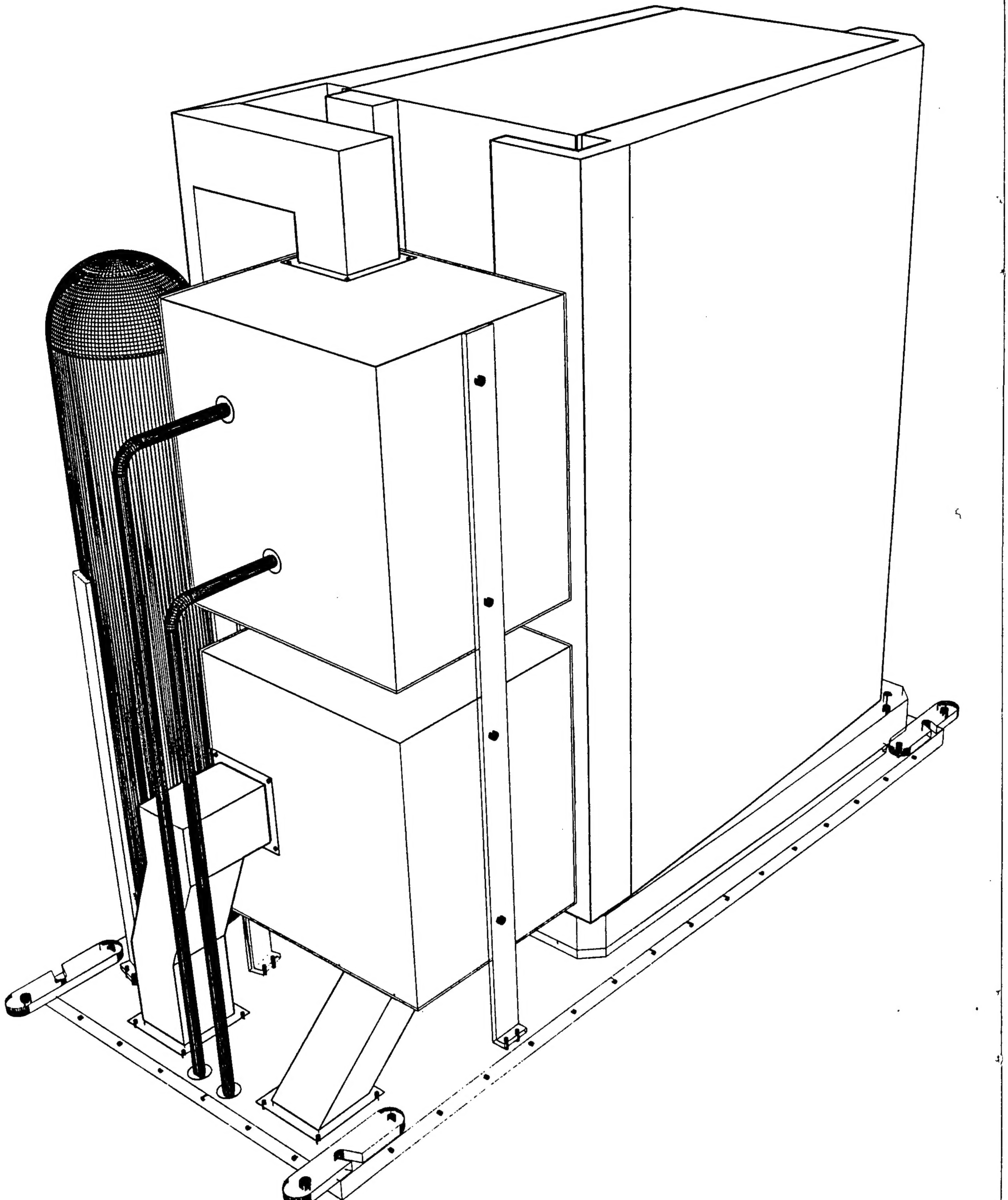

STEAM PIPE


ADIABATIC COLUMN WITH
SUPPORT LEGS


METHANE AND CARBON DIOXIDE PIPE
FOR OUTPUT FROM ADIABATIC COLUMN







FUEL CELL ASSEMBLY